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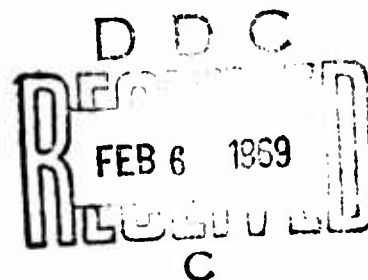
# UTILIZATION OF TIME/FREQUENCY IN COLLISION AVOIDANCE SYSTEMS (CAS)



Minutes of Meeting

August 27-28, 1968

Sponsored By



DEPARTMENT OF TRANSPORTATION  
**FEDERAL AVIATION ADMINISTRATION**  
Systems Research and Development Service  
Washington D.C. 20590

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## FOREWORD

The purpose of the two-day meeting held on August 27-28, 1968, at the Federal Aviation Administration, Washington, D.C., was to discuss the "Utilization of Time/Frequency Techniques in Collision Avoidance Systems." Participating organizations were Government agencies active in the field of time/frequency application.

Presentations made at the meeting, complete or in summary, are included in this publication.

The attendees suggested that a summary of past and present FAA projects for Pilot Warning Instruments (PWI) and Collision Avoidance Systems (CAS) be attached to the minutes for general information. Appendix I contains FAA PWI-CAS projects, Appendix II contains ADSA Chronology, and Appendix III contains the status of PWI projects.

As part of the initial correspondence to respective attendee organizations, replies were solicited for a number of questions. Appendix IV contains the August 1968 questionnaire and a matrix of replies received.

Appendix V contains a December 1968 questionnaire for your reply. Answers to this questionnaire may provide guidance and direction to the FAA as to logical development of the aviation ground facilities required to disseminate "time" for airborne T/F CAS equipment.

Recipients of these minutes are encouraged to complete Appendix V, clip out and return it in the self-addressed envelope enclosed within a few days after receipt. Results will be tabulated and made available to recipients.

ATTENDEES

Time/Frequency Utilization Meeting

August 27-28, 1968

<u>NAME</u>	<u>ORGANIZATION</u>
O. E. McIntire, Chairman	FAA
R. M. Buck	FAA
J. L. Brennan	FAA
R. M. Nerheim	FAA
P. J. LaRoche	FAA
R. Biermann	FAA
T. J. Simpson	FAA
A. Bradley	FAA
A. H. Jessell	FAA
C. E. Dunmire	FAA
A. Moody	FAA
F. L. Frisbie	FAA
F. S. Kadi	FAA
R. L. Huff	USAF/WPAFB
W. Rustenburg	USAF/WPAFB
I. Mirman	USAF
B. Wieder	FSSA/DOC
Major W. J. Delaney	AFSC/SCTSE
T. C. Viars	USAECON - Avionics Lab.
G.M.R. Winkler	USNO
R. T. Moore	USNO
R. G. Hall	USNO
Robert M. Boyd	USNO
G. Kamas	NBS
D. D. Davis	NBS
E. L. Kirkpatrick	NAFS
M. Raditz	N.A.D.C.
J. Hinds	N.A.D.C.
G. Weiffenbach	APL/JHU
A. C. Schultheis	APL/JHU
O. J. Stanton	NASA, RET.
A. R. Chi	NASA/GSFC
F. G. Major	NASA/GSFC
H. L. Anderton	NASA
L. D. Goolsby	NASA
S. C. Laios	NASA
M. E. Shawe	NASA
W. Allen	NASA
C. Laughlin	NASA
E. P. Steele	NASA/ERC Code ES
P. E. Pakos	USCG/EEE-4
C. E. Potts	USCG/EEE-4

M. J. Pozesky  
Gene Jensen  
O. Shames  
E. Hafner  
J. A. Murray  
R. R. Stone  
R. A. Hashimoto

NAVY/PM6  
NAVY/CNO  
NAVY  
USAECON - ECL  
NRL/Code 5424D  
NRL/Code 5424  
USAF/AFXOXYC

Utilization of Time Frequency Techniques in  
Collision Avoidance Systems

August 27-28, 1968

AGENDA

Opening Remarks	Robert M. Buck
Welcome	John A. Weber *
Federal Aviation Administration Time/Frequency - Collision Avoidance Program	John L. Brennan **
Relationship of Time/Frequency - CAS to Future T/F Systems	Philip J. LaRochelle
Brief Review of the Collision Avoidance Problem and Discussion of Time/Frequency - CAS Ground Station Factors	Owen E. McIntire
Remarks on World-Wide Time Synchronization by VLF	Mr. A. R. Chi
Precise Time and Time Interval (PTTI) Activities and Plans (USAF)	Mr. E. L. Kirkpatrick
Discussion of Synchronization by Transportable Clocks	Mr. A. C. Schultheis
Use of Loran-C for Timing	LCDR P. E. Pakos
Loran-C/D Systems Concept	Mr. W. Rustenburg
Timing Potential of Loran-C/D	Dr. B. Wieder
Navy Time/Frequency Programs	Mr. M. Pozesky
Application of Time/Frequency Techniques in Military Station Keeping	Mr. R. L. Huff
Satellite Synchronization	Dr. G. C. Weiffenbach

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\* In opening remarks

\*\* Paper not included in minutes

✓ Satellite Tracking and Data Acquisition (STADAN)  
Frequency Combiner and Microelectronic Clock

Mr. M. E. Shawe

Astrodata Timing  
GEOS Time Synchronization  
ATS Time Synchronization

Mr. S. C. Laios

Satellite Synchronization Techniques

Messrs. W. K. Allen/  
J. G. Dunn

World-Wide Time Review

Dr. G.M.R. Winkler

Remarks on the Application of RF Spectroscopy of  
Stored Ions to Frequency Standards

Dr. F. G. Major

### Opening Remarks

The meeting was opened by Mr. Robert M. Buck, Federal Aviation Administration, Systems Research and Development Service, Detection Systems Branch, who welcomed the attendees and expressed his appreciation for their participation. Mr. Buck introduced Mr. John A. Weber, Director, Systems Research and Development Service.

Mr. Weber discussed the Federal Aviation Administration's role in development of a Time/Frequency Collision Avoidance System (CAS). He pointed out that the system utilizes precise time ordered techniques requiring highly accurate time synchronization of ground and airborne stations. He also pointed out that since the procurement, implementation, and maintenance of the ground station network would be the responsibility of FAA and since the agency had little past experience in precise time and frequency techniques, the agency had invited Government experts in the field to obtain their views.

Mr. Weber stated that the purpose of this meeting was to assist us in determining the best method for establishing and maintaining precise synchronous time, and to this end it was our desire to find out what work had been done, is being done, and remains to be done to meet our responsibilities. He pointed out that since we all work for the same Government

and are subject to similar budget considerations, it behooved us to determine the resources that are available elsewhere to help us and, similarly, how can our work help others. Mr. Weber concluded by expressing his appreciation on behalf of the FAA for the interest and attendance.

At the conclusion of Mr. Weber's remarks, Mr. Buck introduced Mr. John L. Brennan, FAA, Air Derived Separation Assurance (ADSA) Subprogram Manager.

Mr. Brennan stressed the general purpose of the meeting. Specifically, he stated that we wish to determine how best to establish and maintain synchronous time to the accuracies required for CAS ( $\pm 0.5 \mu s$ , 3 sigma, as currently described), and while our overall program would be described briefly for background purposes, discussions should be restricted to those aspects relating to time synchronization. Mr. Brennan distributed the latest revision of the CAS technical description as developed by the Air Transport Association. He explained that the description is updated periodically as a result of meetings of the ATA's CAS Technical Working Group (TWG) and that undoubtedly there would be further revisions forthcoming. He stated that based on prior work done in the area by FAA and others, the conclusion was reached that, under the current state-of-the-art, the T/F technique offered the greatest potential for a CAS system.



Mr. Brennan went on to say that the system described by the TWG is a time ordered system utilizing three second epochs, each epoch being divided into 2000 individual "time slots" of 1500  $\mu$ s each. One, and only one, aircraft transmits in a time slot, thus eliminating the mutual interference problem. Three threat evaluators are used. They are (1) Tau ( $\tau$ ) which is defined as range divided by range rate (a tau alarm condition existing when it decreases below a certain value); (2) an altitude sort; and (3) a minimum range alarm.

Range is measured by computing one-way propagation time. This is possible because all aircraft essentially have the same time and know when every other aircraft starts its transmission. Range rate is determined from the doppler shift of a 200  $\mu$ s RF burst. Barometric altitude is exchanged between aircraft by pulse position modulation, and a minimum range alarm is included to overcome the unreliability of the doppler shift measurement in slow closure rate cases.

For a maneuver alarm to occur, either the  $\tau$  and altitude alarm conditions must be met simultaneously, or the minimum range and altitude alarm conditions must be met simultaneously.

Mr. Brennan stated that under present plans, the vehicle for transmitting common time to aircraft would be a network of ground stations, all synchronized to a single master time. The current ATA schedule calls for test and evaluation of hardware to begin approximately

June of 1969 with implementation hoped for in 1971. Therefore, our most immediate need for time synchronization techniques is in the CAS area. However, Mr. Brennan stated, it is obvious the precise time and frequency techniques can be utilized for other aeronautical functions as well, and we have a program to investigate these applications.

Mr. Brennan then introduced Mr. Owen E. McIntire, FAA Project Engineer, who served as chairman for the remainder of the meeting. Mr. McIntire introduced Mr. P. T. LaRochelle of FAA, SRDS, Systems Analysis Division.

Presentations made by attendees follow.

## Relationship of T/F - CAS to Future T/F Systems

By

Philip J. LaRochelle

### 1. INTRODUCTION

A. The Systems Analysis Division is currently exploring the potential system improvement in national air space (NAS) performance that could be provided by recent advances in modern technology.

B. We are concerned with assessing this technology in terms of overall system performance of capacity, safety and cost - and with the steps required for the compatible integration of new elements into future NAS designs.

C. We recognize the possibility that our present manual air traffic control system, although fully automated to operate like the manual system, may not be capable of adequate performance in the 1980 and beyond timeframe.

D. We are concerned further with developments of new and revolutionary large system developments of the military that will impact on the common civil/military requirements of future NAS designs.

E. Recent advances in techniques for establishing and maintaining precisely synchronized time and frequency references have emerged as a significant contender for meeting the air traffic control requirements of both civil and military air space users.

F. These techniques are the basis of time ordered system concepts that consider cooperative airborne and ground equipment that have the capability for establishing precise time synchronization to a single common timing source. This common time reference is used as the common reference for

the exchange of system data between aircraft and between aircraft and ground stations. Appropriate data processing at either ground or airborne stations then provides for many integrated system functions from a single basis system design.

G. Civil air traffic control functions that can be provided include data acquisition, navigation, communication and landing aids, as well as an independent air-to-air CAS function. Many military functions, such as command and control, weapons delivery, IFF, and tactical air traffic regulation can also be provided by advanced T/F and integrated systems designs.

H. A review of the military activity reveals over two dozen activities within the three military departments that are involved to varying degrees with system applications of T/F and in integrated system developments. We are all aware of the ATA decision and its program to develop a time ordered CAS for airlines use. We recognize industry efforts to further develop additional T/F system designs that will meet the economic constraints of the general aviation aircraft owner. Additional design analyses by NASA and the military include satellite vehicles to provide a possible common communication, navigation, and ATC functions.

## 2. T/F SYSTEMS CONCEPT STUDY

A. We thus find ourselves faced with several significant potential problem areas that require resolution.

First - Assuring compatibility between the FAA/DOD/ATA T/F activity.

Second - Defining common civil/military system requirements, particularly as they apply to ground stations and frequency assignments.

Third - Development of Design criteria that will permit an orderly expansion of the imminent ATA CAS implementation to incorporate other NAS/military functions.

Fourth - Desire to reduce duplication of effort in exploratory Research and Systems design areas.

B. A first step in solving these problems was taken by the FAA in initiating a contract study effort to analyze the potential improvements to civil air traffic management that would be achieved by the broad integrated systems application of T/F technology to present day NAS functions. Five specific tasks are included in the effort:

Task 1 - Studies the present state-of-art of precision oscillators, synchronization techniques, and precise timing performance.

Task 2 - Defines the capability of T/F when applied to the individual functions, such as Data acquisition, Navigation, Communication, landing aids, station keeping and CAS.

Task 3 - Assesses the performance that may be achieved when the many individual functions are integrated into a single system concept. This Task also compares T/F system performance with that of the present NAS design.

Task 4 - Provides a cost/effectiveness analysis of T/F techniques as they may be incorporated into future NAS designs.

Task 5 - Provides for R&D recommendations that are based on areas requiring further analysis, limitations in T/F technology and current civil/military program activity.

C. We have had some difficulty with time phasing and adequate documentation under this contract. The anticipated delivery date of a satisfactory report is now scheduled for about November of this year.

D. Although the study is not complete, preliminary results indicate the following general conclusions:

(1) Presently, available synchronization methods of achieving system master time, as referenced to a common single timing reference, are capable of providing adequate performance for DME, navigation, data acquisition, landing aid, station keeping, and airborne CAS.

(2) These six functions can be provided in a single avionics package, thus potentially reducing the number of current avionics equipments.

(3) Timing requirements for T/F NAS ground station appear to be the same order for accuracy as for the ATA CAS ground stations, i.e., about .1 to .5 microseconds.

(4) Although means to establish and maintain precise time references to secondary ground stations from a single master station were studied, a final recommendation has not yet been made.

E. For this purpose we plan an in-house analysis of the significant system contenders currently being considered by the Military, NASA, and FAA. They include such concepts as being developed under the following programs:

- (1) ICIN and navigation and tactical satellite activity of Air Force
- (2) CNI, EELS, and ULE activity of Navy
- (3) ATARS, STARS, and TOTES activity of Army
- (4) TULACS effort by the Marine Corps, and
- (5) FAA's T/F System concept development

F. We plan further to define the 1975-1980 system requirements in terms of system loads, technical problems and requirements, and perform appropriate trade-off and cost effectiveness analyses. We hope in this manner to develop preliminary design criteria and detailed descriptions of interface requirements necessary for T/F engineering design or for other advanced techniques as they become available. In essence we plan to "confirm or "deny" the use of T/F for future NAS deployment.

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EELS = Electromagnetic Electronic Locating System

ULE = Unit Locating Equipment

ATARS = Army Tactical Airspace Regulation System

STARS = Synchronized Time Automated Reporting System

TOTES = Time Ordered Techniques Experimental System

TULACS = Tactical Unit Location and Control System

### 3. RELATIONSHIP TO FUTURE T/F SYSTEMS

A. In considering the title of this presentation, i. e. , "The Relationship of Time Ordered CAS to Future T/F Systems," we find ourselves somewhat in the position of the cart before the horse. In particular we find that:

one - A firm decision has been made by the airlines to develop and procure operational T/F CAS devices by early 1972.

two - These devices require the procurement and deployment of an unspecified number of ground stations.

three - The ATA-CAS design has a capability for data acquisition, DME, and flight following, in addition to the CAS function.

four - The ATA Type CAS equipment is economically justified only for airline use at this time.

five - Sufficient system designs and comparative analyses have not been accomplished to date either to realistically justify the use of T/F for civil air traffic control or to specify the characteristics required for NAS T/F ground stations.

B. It thus appears that we should concentrate at this meeting with world-wide and ground station timing requirements as they meet the needs of the singular CAS function.



**Review of the Collision Avoidance Problem and  
Discussion of T/F - CAS Ground Station Factors**

by

Owen E. McIntire

The illustrative pages which follow describe

1. The CAS problem
2. The need for a cooperative T/F CAS
3. The desirability of U.S. National Standards
4. The T/F - CAS technique
5. The synchronization problem, and
6. Accuracy requirements

Since errors were in the original papers, corrections have been made prior to publication. Much of the data is essential in T/F ground station development; therefore, other changes will be made, as necessary, to reflect state-of-the-art changes or other pertinent factors.

**OBJECTIVE** — a solution to  
AIRBORNE COLLISION AVOIDANCE  
THE BY  
TECHNIQUE  
OF

THE PROBLEM  
AN AIRCRAFT IN FLIGHT IS FACED WITH THE POSSIBILITY OF A  
MID-AIR COLLISION BECAUSE OF THE PRESENCE OF OTHER  
AIRCRAFT IN THE IMMEDIATE VICINITY

— TO AVOID POTENTIAL COLLISION HAZARDS —  
AN AIRCRAFT PILOT MUST BE

1. DETECTING THE POTENTIAL COLLISION HAZARDS
2. EVALUATING THE POTENTIAL COLLISION HAZARDS
3. IF NECESSARY, PERFORM AN EVASIVE MANUEVER

[THE F.A.A. PROVIDES AIR TRAFFIC CONTROL (ATC)]

TO:

ASSIST THE PILOT IN COLLISION AVOIDANCE  
HOWEVER THIS TECHNIQUE ONLY MEETS THE OBJECTIVE, WHEN  
RULES AND REGULATIONS ARE VOLUNTARILY COMPLIED WITH

THUS:

IT IS OUR PRESENT CONCLUSION - THAT

~ AIRBORNE COLLISION AVOIDANCE ELEMENTS ~  
USING PRECISION TIME AND FREQUENCY CONCEPTS, IS THE

PRACTICAL SOLUTION

TO:

ASSIST THE ATC SYSTEM IN ASSURING SAFE  
OPERATION OF AIRCRAFT

CONCEPTUALLY -

THE TASK OF DETECTION CAN BE EITHER

A. SELF-CONTAINED

1. RADAR, OR

2. INFRARED; OR

B. COOPERATIVE

1. RADAR-BEACON, OR

2. DATA LINK

EXPERIMENTATION AND ANALYSIS HAVE SHOWN

- NO SELF-CONTAINED SYSTEM CAN PROVIDE SUFFICIENT DETECTION RANGE -

• ON ALL TYPES OF INTRUDERS

• UNDER ALL WEATHER CONDITIONS

- TO FORM A BASIS FOR AN AUTOMATIC CAS -

PRACTICALLY

THE FAA. BASED ON EXPERIENCE AND ANALYSIS HAS CONCLUDED

- A COOPERATIVE DETECTION TECHNIQUE IS THE BEST APPROACH -

- TO FORM A BASIS FOR AN AUTOMATIC CAS -

COOPERATIVE DETECTION

RADAR BEACONS • DEPEND ON INTERROGATION AND REPLY BY EACH AIRCRAFT

• THE TOTAL NUMBER OF INTERROGATIONS CAN BE  $n$  (#AIRCRAFT) AND  $n(n-1)$  REPLIES

• ANALYSIS BASED ON KNOWN AIRCRAFT DENSITIES LEADS TO THE CONCLUSION THAT THIS APPROACH WILL NOT PROVIDE AN ADEQUATE UPDATE RATE

DATA LINK (ONE-WAY)

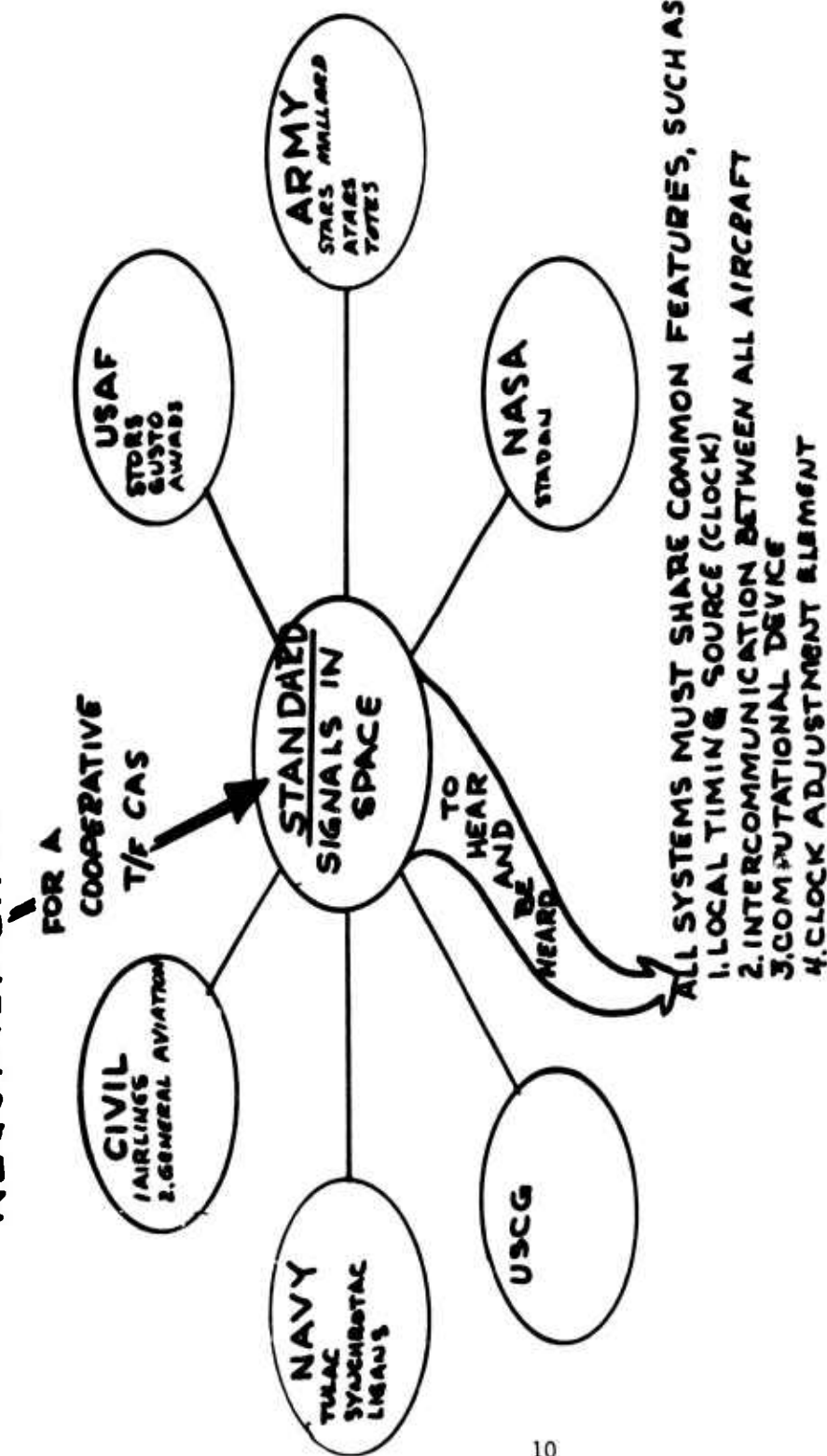
• DEPENDS ON ONE-WAY RANGING USING ACCURATELY SYNCHRONIZED CLOCKS

• ONLY  $n$  TRANSMISSIONS ARE REQUIRED TO RANGE AND COMMUNICATE BETWEEN ALL PAIRS

• THIS FORM OF PRECISE DETECTION IS A PART OF THE PROPOSED

COOPERATIVE - TIME/FREQUENCY COLLISION AVOIDANCE SYSTEM

# REQUIREMENT:



## -IMPLEMENTATION-

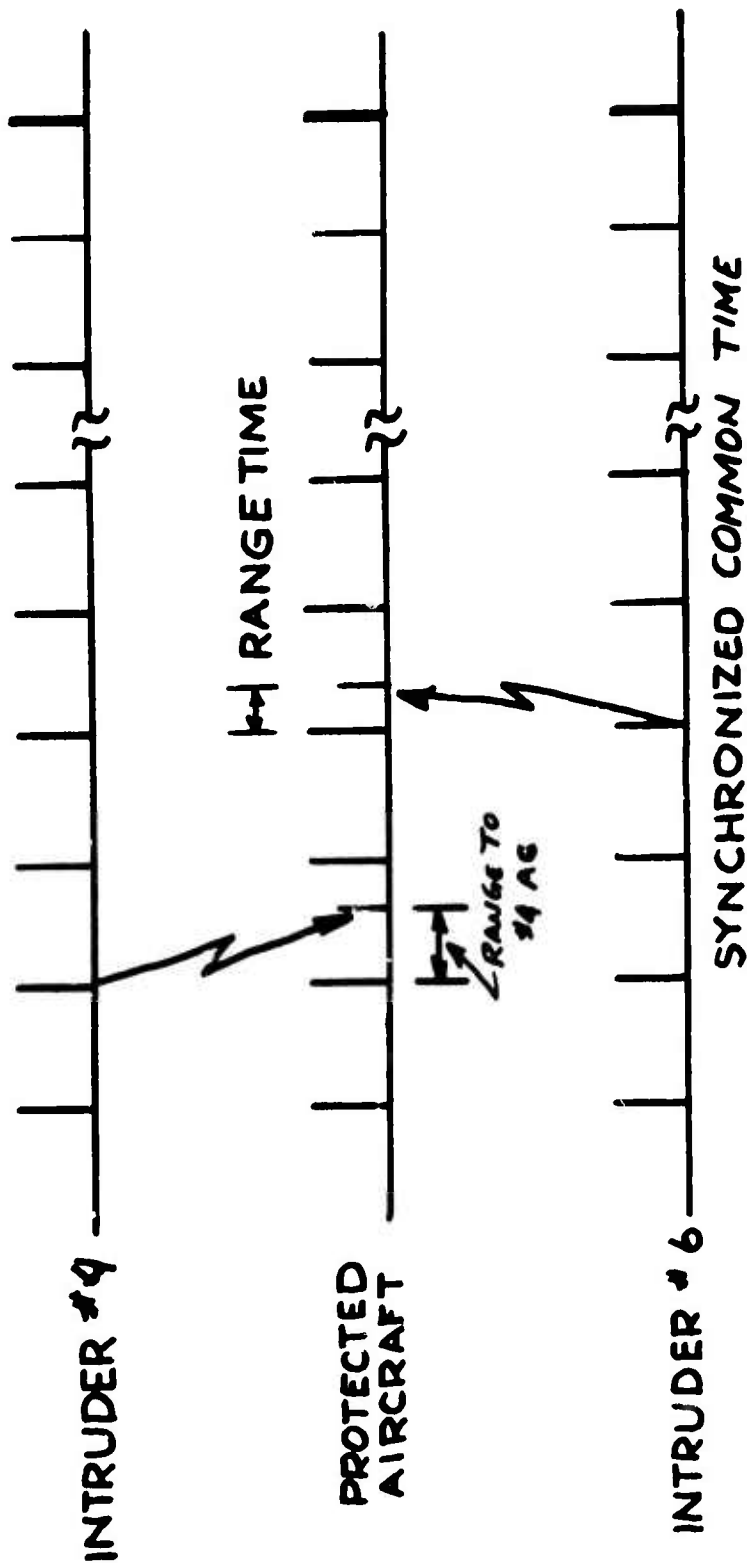
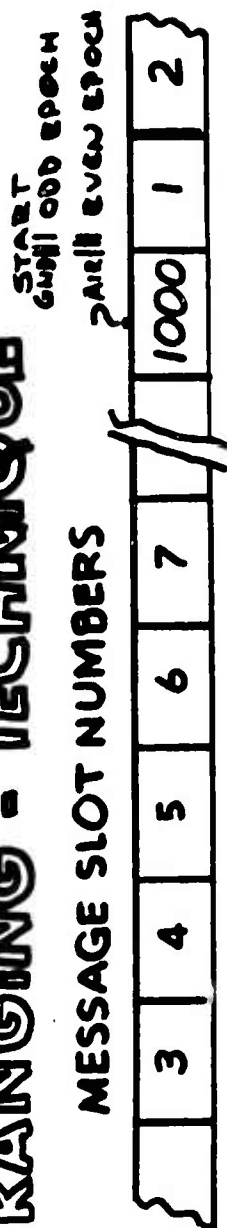
A NECESSARY PREREQUISITE TO SPECIFYING A COMMON SYSTEM UTILIZING PRECISE TIME AND FREQ. SIGNALS IS AN IN DEPTH STUDY OF THE MANNER IN WHICH VARIOUS VEHICLES AND EQUIPMENTS CAN IMPLEMENT THE STANDARDIZED SIGNALS? I.E.

1. THE FIDELITY OF THE SIGNAL REQUIRED?
2. CAN SIGNALS BE USED DIRECTLY OR ONLY INDIRECTLY?
3. WILL ONLY TIME OR FREQUENCY BE REQUIRED? OR WILL BOTH BE NECESSARY?
4. WHAT IS THE NATURE OF MODULATION AND FREQUENCIES INVOLVED?

# CHARACTERISTICS OF SYSTEMS REQUIRING ACCURATE TIME AND/OR FREQUENCY REFERENCE

SYSTEM	FUNCTION	PROPOSED	DEVELOPMENT	IN USE	SECURITY CLASSIFICATION	CARRIER FREQ.	MESSAGE FORMAT		ACCURACY (REQUIRED)				TIME	
							MOD- ULAT- ION	CODING	TIME (EPOCH)	FREQUENCY			LOCAL	WORLD WIDE
										STATION STABILITY REQ. 1 BIT	STATION STABILITY REQ. 2 BIT	STATION STABILITY REQ. 3 BIT		
①				X	UNC	NF	FSK A	VOICE	NA	1000 Hz	1000 Hz	1000 Hz	X	
②			X	X	UNC	AMP	FSK F	RANDOM DIGITAL	NA	1000 Hz	1000 Hz	1000 Hz	X	
③				X	UNC	E-B	Q000 P <sub>2</sub>	NONE	NA	1000 Hz	1000 Hz	1000 Hz	X	
④	NOBITES			X			PHASE	REFERENCE 1	1-100 Hz				NA	CACHED REF/TIME
⑤				X	UNC	AMP	PHASE	REFERENCE 1	1-100 Hz	1000 Hz	1000 Hz	1000 Hz		250 MHz
⑥														
⑦														
⑧														
⑨														
⑩														
ATA	CAS		X	X	UNC	AMP	FSK A	BARKER 11 BIT - 2 BIT PULSE POSITION	3 SEC	1000 Hz	1000 Hz	1000 Hz		0.5 sec (30)

# T/F RANGING - TECHNIQUE



## PRECISE SYSTEM TIMING

- MAKES IT POSSIBLE TO EXTRACT RANGE INFORMATION FROM --
- TIME OF ARRIVAL SCHEDULED TRANSMISSIONS.

### A. COARSE SYNCHRONIZATION

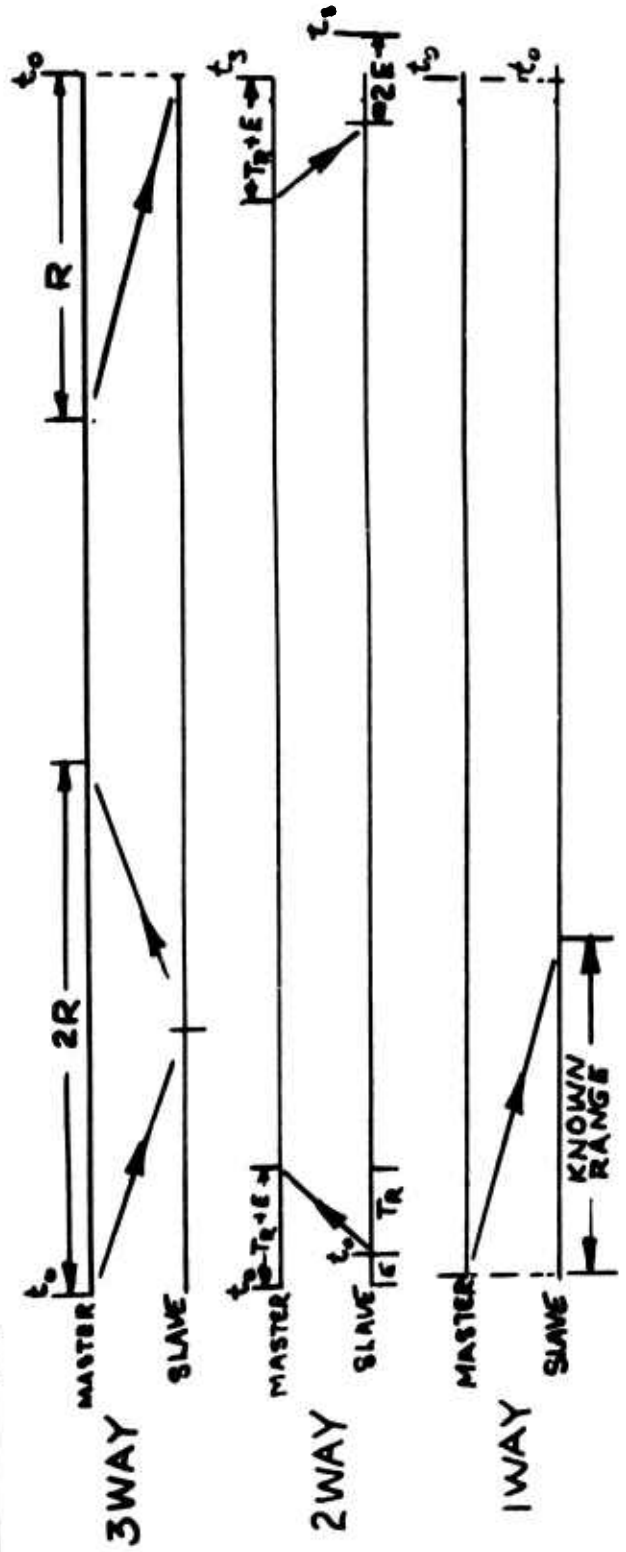
SCHEDULED TRANSMISSIONS REQUIRE SLOT TIME ASSIGNMENT  
TECHNIQUE

THE SYNCHRONIZER COUNTS SLOTS FROM A KNOWN EPOCH START  
TO FIND HIS ASSIGNED SLOT (THIS POSITION IS LATE BY THE PROPAGATION DELAY)  
[SINCE VERY ACCURATE CLOCK SYNCHRONIZATION (TO COMMON TIME) IS REQUIRED,  
IT IS NECESSARY TO REMOVE PROPAGATION DELAY]

### B. FINE SYNCHRONIZATION

EXTRACTION OF RANGE INFORMATION REQUIRES ACCURATE TIMING

#### TECHNIQUE



# THE LITTLE PLANE A DIFFICULT PROBLEM

ATA TECHNICAL CHARACTERISTICS DESCRIBE A CAS HAVING THE FOLLOWING ELEMENTS

1. STABLE OSCILLATOR - FOR -  
A. ACCURATE CLOCK  
B. FREQUENCY STANDARD
2. TRANSMITTER RADIATING CODED PULSES AT  
A. PRECISE REPETITION RATE  
B. PRECISE FREQUENCY
3. RECEIVER-DECODER OF  
A. DOPPLER  
B. PULSE POSITION
4. COMPUTERS, SENSORS AND DISPLAYS <sup>30,000</sup>  
ESTIMATES OF SYSTEM COST RANGE FROM ~~50~~ TO 50,000 DOLLARS

THIS EXCEEDS THE VALUE OF SMALL AIRCRAFT CLASSES

## THEREFORE

ONE APPROACH TO THE PROBLEM IS TO DEFINE A CERTAIN MINIMUM SYSTEM THAT WILL ASSIST THE SMALL PLANE IN COLLISION AVOIDANCE IN BOTH A BIG AND SMALL PLANE ENVIRONMENT

- \*1. STABLE OSCILLATOR - FOR -  
A. ACCURATE CLOCK  
B. FREQUENCY STANDARD
2. TRANSMITTER TO EMIT CODED PULSES
3. RECEIVER WITH PULSE DECODING
4. DISPLAY DEVICE

\* THE STABLE OSCILLATOR COULD BE OF A TYPE NOT CAPABLE OF MAINTAINING SYNCHRONIZATION WHEN NOT WITHIN RANGE OF A SPECIAL GROUND STATION



## APPLICABILITY OF CRYSTAL CLOCKS

-THE OBVIOUS ADVANTAGE-

LESS<sub>COST</sub> > WEIGHT > VS ATOMIC CLOCK

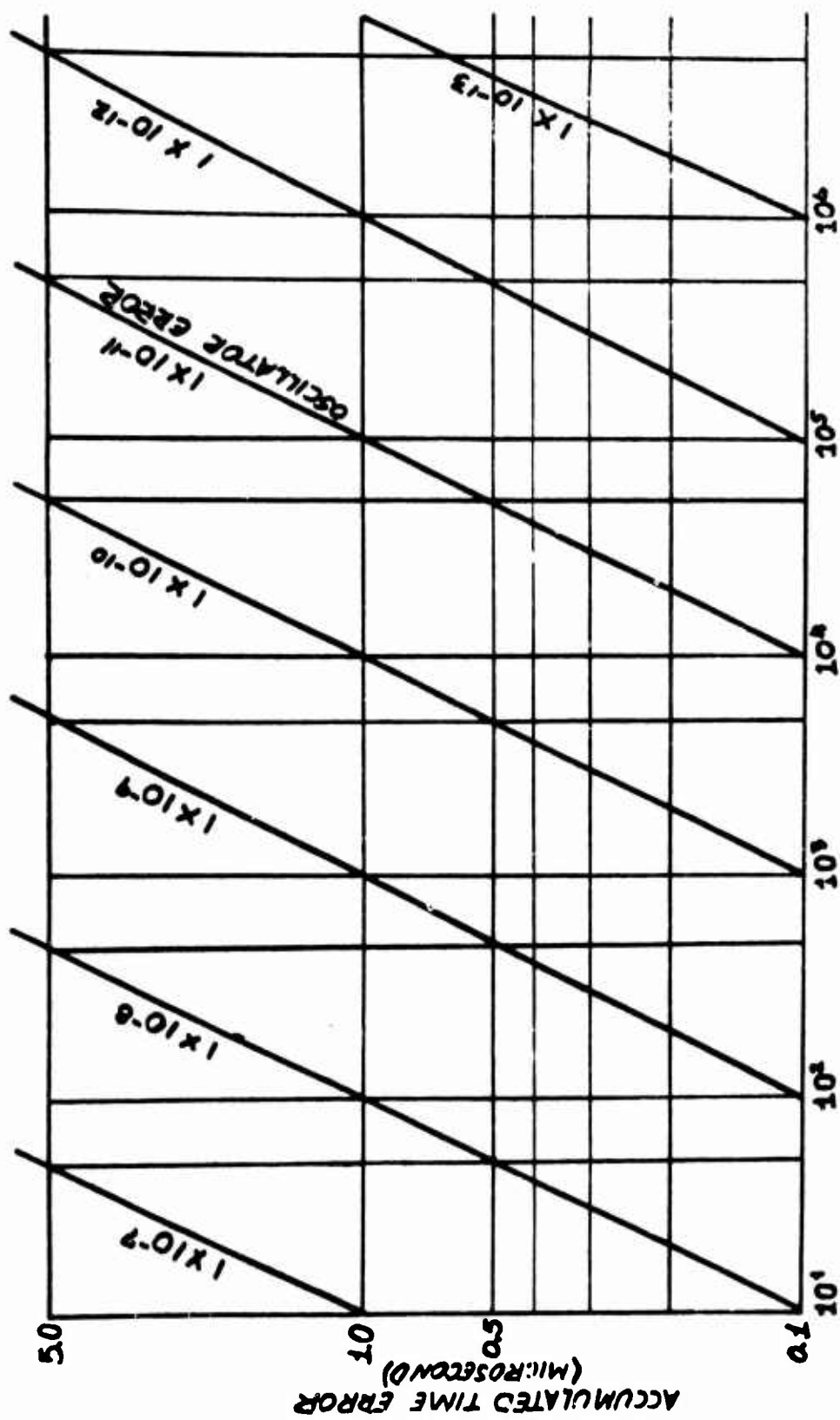
UNFORTUNATELY IN AN AIRBORNE ENVIRONMENT

SETTABILITY > DEMAND FREQUENT RESYNCHRONIZATION  
STABILITY

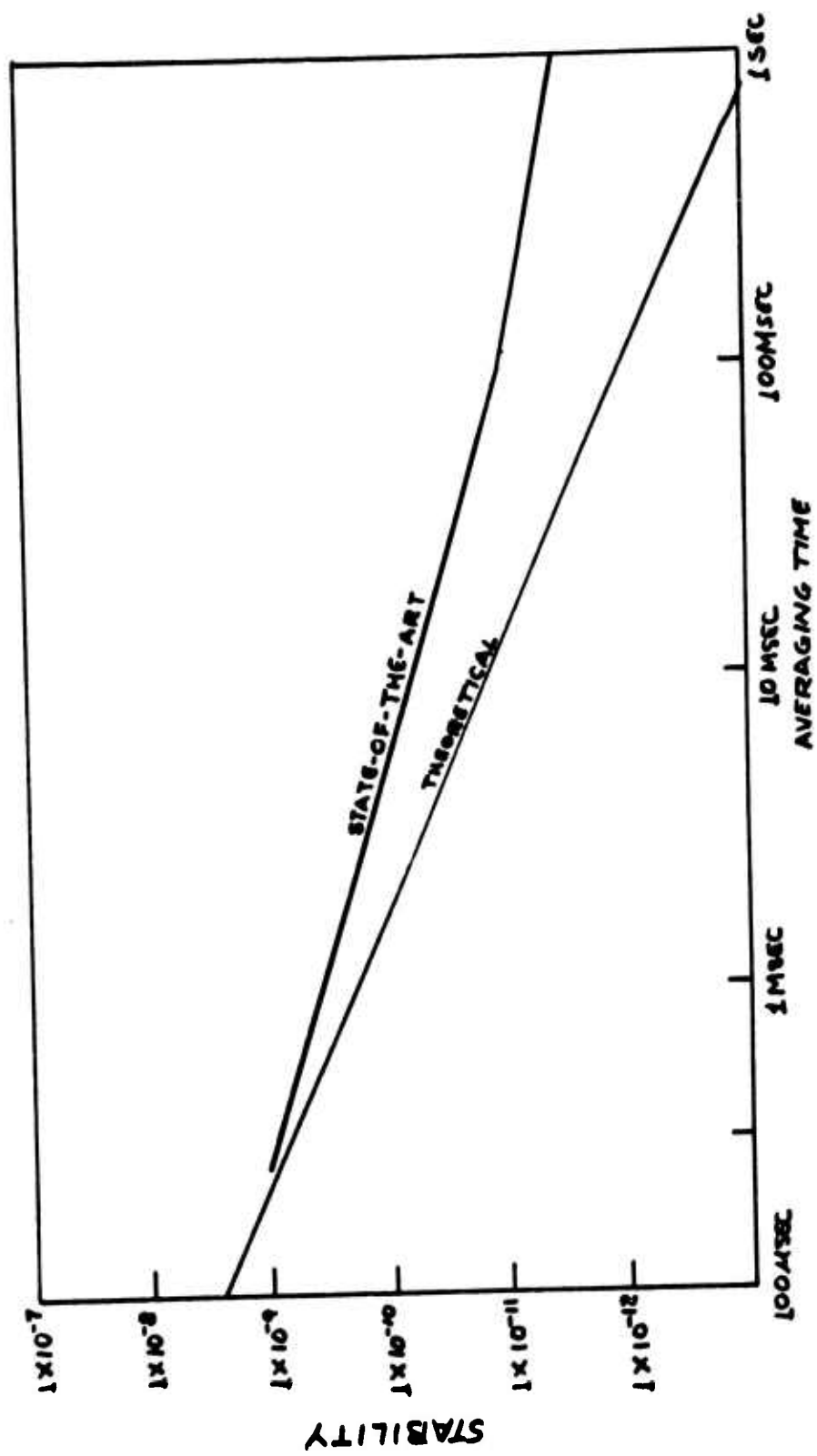
A FREQUENCY ERROR OF 1 PART IN  $10^8$  (ATA SPECIFIED FOR 100 USEC)

REQUIRES RESYNCHING EVERY 100 MSEC  
TO MAINTAIN SYSTEM CLOCK ERRORS  
WITHIN FIVE OF A REFERENCE CLOCK

REFERENCE TO THE THEORETICAL CRYSTAL OSCILLATOR CURVES  
SHOWS LITTLE IMPROVEMENT CAN BE OBTAINED?



TIME BETWEEN RESYNCHRONIZATIONS (SECONDS)  
ACCURACY VS SYNCHRONIZATION



## STABILITY VS TIME CRYSTAL OSCILLATORS

## GROUND STATIONS - ARE REQUIRED TOO

1. INITIALLY SYNCHRONIZE AIRCRAFT ON THE GROUND
2. PERMIT COARSE AND FINE SYNCHRONIZATION
3. PERMIT RESYNCHRONIZATION (IN EMERGENCIES) ABOVE MALFUNCTIONS

## ACCURACY OF GROUND STATIONS (SECONDARY STANDARD) - ATA SPECIFIED -

THE TIMING OF THE EACH START PULSES OF EACH GROUND STATION SHALL BE KEPT WITHIN  $\pm 0.5 \mu\text{SEC}$  (3 $\sigma$  VALUE) OF A DESIGNATED CAS WORLD WIDE TIME.

WHICH STATES IN EFFECT: THE RMS OF ONE OF THE SYNC PROCESS AND THE RMS ERROR OF THE GROUND STATION MUST NOT EXCEED 167 NSEC.

$\therefore$  THE GROUND STATION MUST NOT EXCEED APPROX. 100 NSEC DURING THE TIME INTERVAL BETWEEN SYNCHRONIZATIONS

## ACCURACIES OF TIMING STANDARDS - IN TERMS OF 100 NSEC ABILITY

CRYSTAL OSCILLATOR	< 12 HOURS	REDUNDANT: C <sub>3</sub> -BEAMS
R <sub>4</sub> -VAPOR CELL	12 HOURS	OF X <sub>2</sub> AL <sub>1</sub> /C <sub>3</sub>
C <sub>3</sub> -BEAM	5 DAYS	

## GROUND STATION SYNCHRONIZATION IS ESTABLISHED BY -

1. ACCURACY  $\rightarrow \approx 100 \text{ NSEC}$  { FLYING CLOCK
2. COVERAGE  $\rightarrow \approx 1000 \text{ MILES}$  { LORAN-C
3. ACCESSABILITY  $\rightarrow \text{GOOD}$  { SAT

## MONITORING OF THE GROUND STATION

1. - SAME -
  2. - " -
  3. - " -
- { LORAN-C  
OMEGA  
VLF

TYPE	FREQUENCY STABILITY			TEMPERATURE	MAGNETIC FIELD	INTRINSIC REPRODUCIBILITY	ACCURACY	DRIFT RATE	WARM-UP TIME	RELIABILITY
	0.001 SEC	0.01 SEC	1 SEC							
CURRENT COMMERCIAL										
HERBERT-PACKARD C <sub>2</sub> -BEAM	7X10 <sup>-9</sup>	8X10 <sup>-11</sup>	8X10 <sup>-12</sup>	2X10 <sup>-8</sup>	0°-50°C 5X10 <sup>-12</sup>	2 GAUSS 1X10 <sup>-12</sup>	5X10 <sup>-12</sup>	1X10 <sup>-11</sup>	<1X10 <sup>-14</sup> PER LINE	QSR. 40,000 QSR. 40,000
R <sub>2</sub> -OPTICAL GAS CELL	5X10 <sup>-10</sup>	1X10 <sup>-11</sup>	1X10 <sup>-11</sup>	5X10 <sup>-12</sup>	0°-50°C 5X10 <sup>-12</sup>	ANY ORANGE 5X10 <sup>-12</sup>		<1X10 <sup>-14</sup> PER NO.	LOH.	
H-MASER	5X10 <sup>-10</sup>	9X10 <sup>-11</sup>	8X10 <sup>-11</sup>	2X10 <sup>-11</sup>		5X10 <sup>-12</sup>	2X10 <sup>-12</sup>	<1X10 <sup>-14</sup> PER LINE	4 DAYS	
H-MASER (NBS)	5X10 <sup>-10</sup>	9X10 <sup>-11</sup>	1X10 <sup>-11</sup>	1X10 <sup>-11</sup>			2X10 <sup>-12</sup>		4 DAYS	
GENERAL TRL TRACER R <sub>2</sub> -OPTICAL GAS CELL (CONTINUED)	5X10 <sup>-9</sup>	1X10 <sup>-10</sup>	1X10 <sup>-11</sup>	5X10 <sup>-12</sup>	-100 to 50°C 1X10 <sup>-12</sup>	5X10 <sup>-12</sup>			1.0 H.	
R <sub>2</sub> -OPTICAL GAS CELL (NBS)	5X10 <sup>-9</sup>	1X10 <sup>-10</sup>	1X10 <sup>-11</sup>	5X10 <sup>-12</sup>	-50°C to 50°C 1X10 <sup>-12</sup>	5X10 <sup>-12</sup>			1.0 H.	
R <sub>2</sub> -OPTICAL GAS CELL (STANDARD)	5X10 <sup>-9</sup>	1X10 <sup>-10</sup>	1X10 <sup>-11</sup>	5X10 <sup>-12</sup>	0° to 50°C 1X10 <sup>-12</sup>	5X10 <sup>-12</sup>	2X10 <sup>-12</sup> - 1X10 <sup>-11</sup>		1.0 H.	24,000 H
GENERAL RADIO CO. R <sub>2</sub> -OPTICAL GAS CELL	5X10 <sup>-10</sup>	1X10 <sup>-11</sup>	1X10 <sup>-11</sup>	1X10 <sup>-12</sup>	0° to 50°C 1X10 <sup>-12</sup>	5X10 <sup>-12</sup>			1.0 H.	
NATIONAL COMPANY C <sub>2</sub> -BEAM (MILITARY)			5X10 <sup>-11</sup>	4X10 <sup>-12</sup>	0° to 50°C 5X10 <sup>-12</sup>	2 GAUSS RD 1X10 <sup>-11</sup>	5X10 <sup>-12</sup>	2X10 <sup>-11</sup>	20 MIN @ 25°C	10,000 H
C <sub>2</sub> -NIM (COMM.)			5X10 <sup>-11</sup>	2X10 <sup>-12</sup>		2 GAUSS RD 1X10 <sup>-11</sup>	5X10 <sup>-12</sup>	5X10 <sup>-11</sup>	1.0 H.	10,000 H
UNDER DEVELOPMENT										
THALLIUM				2X10 <sup>-12</sup>			10 <sup>-12</sup>			
BARIUM OXIDE				2X10 <sup>-12</sup>			10 <sup>-12</sup>			
FUTURE DEVELOPMENT CONCEPTS										

FREQUENCY MHz	RESONANCE WIDTH Hz	OPERATIONAL PRINCIPLE	VOLUME CM <sup>3</sup> ETC.	POWER	WEIGHT LBS	PRINCIPAL ADVANTAGE	PRINCIPLE LIMITATION	UNIT COST (APPROX)	COMMENTS
9192.631770	250	ATOMIC BEAM (PASSIVE)	1.2		60	RESISTANCE TO EXTERNAL MAGNETIC FIELDS	SUBJECT TO EXT. MAG. FIELDS SHORT TERM STAB.	\$14.8K	
6826.622608	200	OPTICAL PUMPING IN GAS CELL (PASSIVE)	1.0	200W	40	SIZE & WEIGHT	APPROXIMATE CALIBRATION	\$6.0K	
1420.402181	1	ATOMIC BEAM (ACTIVE)	26.0		80	FREQUENCY STABILITY	SIZE WEIGHT	\$55.0K	
			6.0		30			\$520K	
			0.6		24			\$125K	
			0.3		14			\$90.0K	
			1.0		39			\$10.0K	
			1.0		40			\$3.0K	
			1.2		79			7-6.6K \$15.0K	
			6.5		105			\$10.0K	
2/310.3		ATOMIC BEAM (PASSIVE)							
18702.0		MULTICOLOR BEAM (PASSIVE)				RESISTANCE TO EXT. MAG. FIELDS SIZE & WEIGHT	SHORT TERM STABILITY		

**T/F GROUND STATION SYNCHRONIZATION  
POTENTIAL SOURCES OF TIME AND TIME INTERVAL**

TECHNIQUE	PARTICIPATING ORGANIZATION	SPONSOR	REFERENCE RECOVERABLE	PRECISION	SYNCHRONIZATION ACCURACY	COVERAGE	PROPAGATION ANOMALIES
VLF	ARMY (ECOM) HENLETT-PAC RANG NAVY USNO	NBS, NAVY	TIME INTERVAL	1 PART IN $10^{10}$	200 NS (THIS CAN BE MAINTAINED AFTER INITIAL SYNCHRONIZATION) 50 NS	WORLD-WIDE (POSSIBLE)	
DUAL FREQUENCY VLF	NBS NASA NAVY USNO	NASA	TIME INTERVAL		50 SEC	WORLD-WIDE (POSSIBLE)	0.2 SEC DURING DAY 0.6 SEC DURING NIGHT
OMEGA	NAVY (NELC)	NAVY			5 SEC (POSITION FIX POSSIBLE DURING THE DAY AND 1.5 MILES AT NIGHT)	WORLD-WIDE (EVENTUALLY)	N.A.
LORAN-C -D AIR FORCE	COAST GUARD DOD AIR FORCE	NAVY	TIME INTERVAL TIME		0.1 TO 0.5 SEC 10 TO 30 NS	18 TO 600 MILES (GROUND WAVE) 600 TO 2000 MILES (SKY WAVE)	0.1 SEC FOR GROUND WAVE UP TO 600 MILES 0.5 SEC OVER 600 MILES > 1.5 SEC
TRANS-PORTABLE CLOCK	USAF	USAF	TIME INTERVAL TIME		0.5 NS	WORLD-WIDE	—
SATELLITE	BELL LABS, NBS JPL, NAVAL OBSERV STUDY, RELIANCE	NASA NAVY	0.8 TO 0.8 SEC		0.4 TO 0.8 SEC	12000 MILES (ONE SAT)	AT VHF 1.0 SEC

STATUS	REFERENCE STANDARD	NOTES	FUTURE RESEARCH PLANS
OPERATIONAL	CRYSTAL PHASE LOCKED TO C <sub>60</sub> -BEAM	DIFFERENT VLF STATIONS AROUND THE WORLD TRANSMIT TIME SIGNALS ON VLF. THIS DATA APPLIES TO THE NBS STATION AT FORT MONMOUTH, NJ	
EXPERIMENTAL	CRYSTAL PHASE LOCKED TO R <sub>6</sub> GAS CELL	ACCURACY MAY POSSIBLY BE IMPROVED TO SAME	
EXPERIMENTAL	ATOMIC STANDARD	TIME SYNCHRONIZATION ACCURACY NOT KNOWN BUT MAY BE AS GOOD AS 1 μSEC	
OPERATIONAL EXPERIMENTAL	R <sub>6</sub> GAS CELL REFERENCED TO USNO	PRECISION TIME SYNCHRONIZATION IS ONLY AVAILABLE ON THE EAST COAST CHAIN	
	C <sub>60</sub> -BEAM	TRANSPORT TIME OF 31 DAYS DEMONSTRATED WITHOUT RESYNC. SYNC IMPROVEMENT TO BELOW 0.1 μSEC FORECAST. RELATIVISTIC EFFECTS MUST BE CONSIDERED	
	ATOMIC STANDARDS	GLOBAL CAPABILITY SYNC ACCURACY MAY EXCEED 0.1 μSEC	



REMARKS ON  
WORLD WIDE TIME SYNCHRONIZATION BY VLF

Andrew R. Chi, Code 521

NASA, Goddard Space Flight Center

The technique of using dual VLF transmissions for time synchronization of remote station clocks is developed jointly by the National Bureau of Standards who controls the WWVL transmitters and Goddard Space Flight Center where the data is collected and analyzed. Timing information is obtained from the relative phase delay of the two received signals for a given propagation path. If the propagation path length is assumed to be constant, the cycle of a received carrier can be determined directly from the relative phase delay.

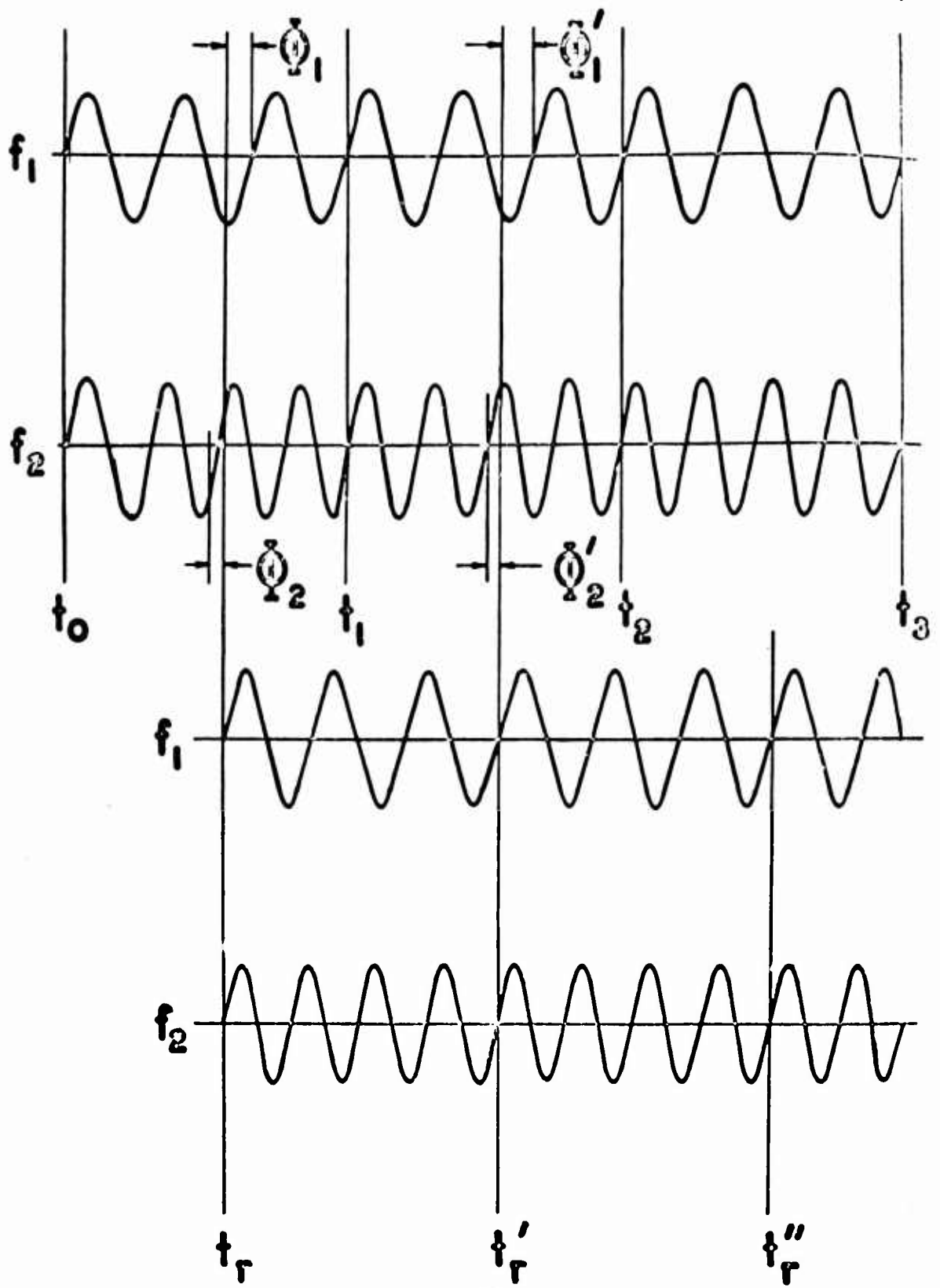
In practice, a specially designed receiver is used for the determination of the relative phase of the two received signals. However, two separate VLF phase tracking receivers can be used. In either approach, the receiver delay is removed by the use of a calibrator which generates a spectrum of the frequencies at 100 Hertz separation in the VLF band. Furthermore, the calibrator frequencies are synchronized to the 1 pps of a local clock at the receiving site. A pictorial presentation of the received signals and the calibrating signals is shown in Figure 1. The two positive going zero crossings of the two signals in the top of the figure occur at  $t_0$ , coincident with a second pulse of the clock at the transmitter. The two calibrating signals in the lower part of the figure have their positive going zero crossing occurring at  $t_r$ , coincident with a received pulse of the clock at the receiver. Since the relative phase of the two signals repeats at periods of the beat frequency, e.g. 10 millisecond for the 100 Hertz separation of the 20.0 and 19.9 kHz transmissions, the ambiguity of time determination to 10 ms will have to be resolved by other techniques such as by the use of WWV time signal transmissions. These ambiguity points are indicated in the figure by  $t_1$ ,  $t_2$ , and  $t_3$  for the transmitted signals and  $t_r$ ,  $t_r'$ ,  $t_r''$  for the calibrating signal.

Phase tracking of a VLF signal is measured by the phase difference between the calibrating signal and the received signal as indicated by  $\phi_1$  or  $\phi_2$  in Figure 1. It is to be noted that the received signal is locked at the positive going zero crossing of a cycle which is a characteristic or design of a VLF phase tracking receiver. The relative phase delay of two signals is determined by  $\phi_1 - \phi_2$ .

The time difference between the clocks at the transmitter and the receiver is given by Equations (1) and (2) in Figure 2. It can also be written in the form of Equations (1), (2), and (4) in Figure 3. In these equations  $n_1 - n_2$  can be either zero or 1 in the first ambiguity region, i.e. 10 ms. Since  $t_p$  and  $\Delta t_c$  in Equation (2) of Figure 2 can not be independently determined, a portable clock is needed to measure  $\Delta t_c$  at least once in order to calculate the propagation delay. Once the propagation delay is known,  $\Delta t_c$  can be determined only through the long-term observation of the behavior of two known clocks.

The experimental results of the received dual VLF signals at Greenbelt for 1966 and 1967 are shown in Figures 4 and 5. The systematic change of any one received signal delay is due to the off-set frequency of the standards which drive the clocks. One should observe that the difference in delay of the two received signals remains relatively constant, indicating the propagation path length is constant. The scattering of the residuals from the systematic trend is the propagation anomaly and the variation of the relative phase control at the transmitter gives an error of one cycle for about each 2 degrees of arc or  $t_2 - t_1 = 0.251 \mu s$  for 20.0 and 19.9 kHz carriers.

In the time determination by dual VLF techniques, the precision is limited therefore by the anomaly of the propagation path length, the accuracy in the determination of the relative phase delay and the control at the transmitter of the relative phase of the emitted signals. The variation of the identified cycle throughout a year has been observed to be about  $\pm 2$  at 20 kHz or  $\pm 100 \mu s$ . Since it is not certain that all of these variations are due to propagation anomaly, especially under the present experimental environment of the transmitters, it may not be justified to use these variations as the lower limit although they do represent the present results. For a given identified cycle, the time comparisons by predicted time difference through VLF data and portable clock measurements has been in the order of  $10 \mu s$ .



$$t_r - t_o = t_p + \Delta t \quad (1)$$

$$= t_p + (\Delta t_p + \Delta t_c) \quad (2)$$

$t_r$  = RECEIVED TIME

$t_o$  = LOCAL CLOCK TIME

$t_p$  = PROPAGATION DELAY

$\Delta t_p$  = PROPAGATION ANOMALY

$\Delta t_c$  = CLOCK DIFFERENCE

FIGURE 2

$$t_r - t_0 = n\tau + (n_1 + \frac{\phi_1}{2\pi})\tau_1 \tag{1}$$

$$= n\tau + (n_2 + \frac{\phi_2}{2\pi})\tau_2 \tag{2}$$

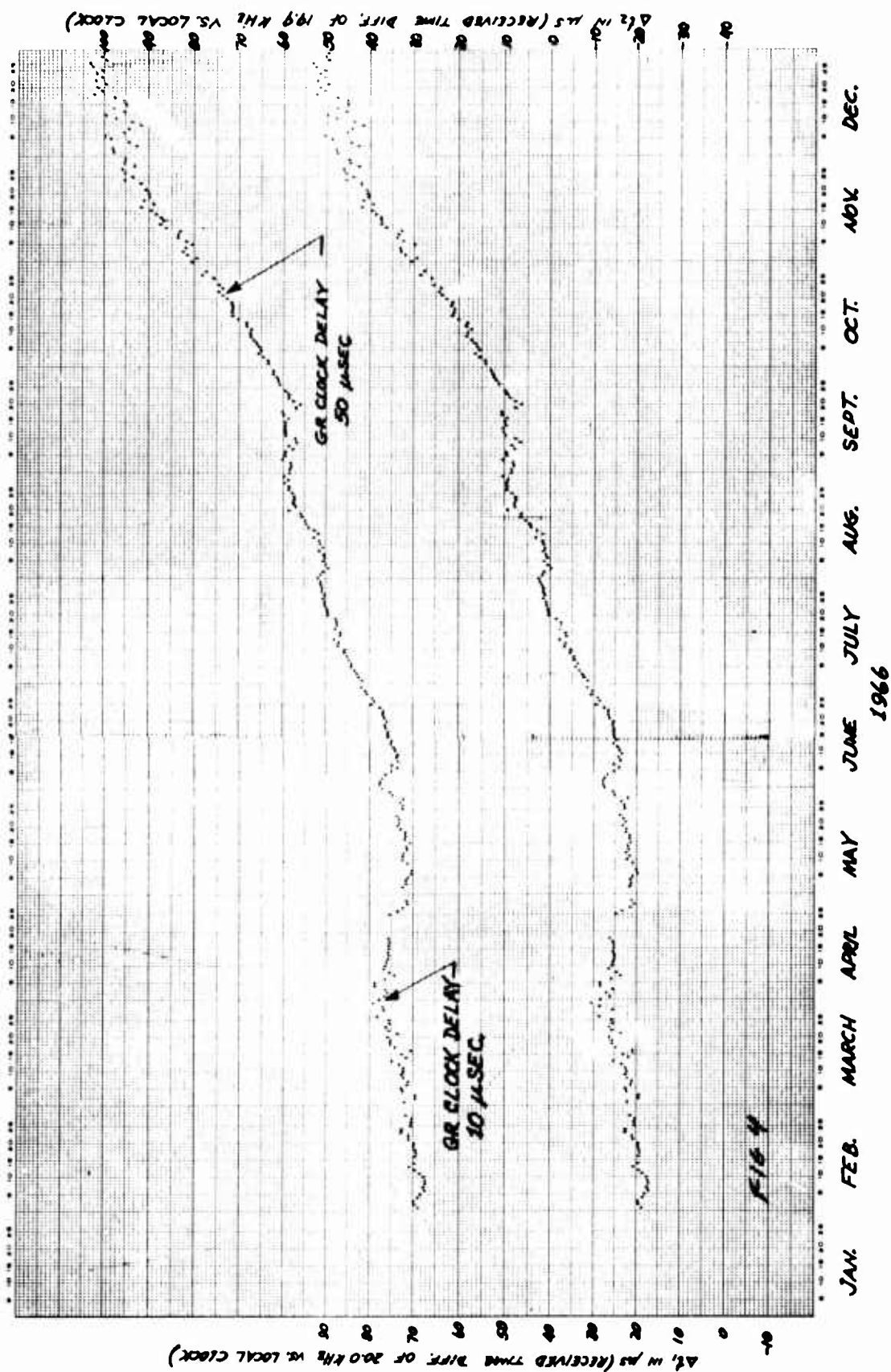
$$(n_2 + \frac{\phi_2}{2\pi})\tau_2 = \left[ (n_1 - n_2) + (\frac{\phi_1 - \phi_2}{2\pi}) \right] \tau \tag{3}$$

$$t_r - t_0 = \left[ n + (n_1 - n_2) + (\frac{\phi_1 - \phi_2}{2\pi}) \right] \tau \tag{4}$$

$$\tau_1 = \frac{1}{f_1} ; \tau_2 = \frac{1}{f_2} ; \tau = \frac{1}{f_1 - f_2}$$

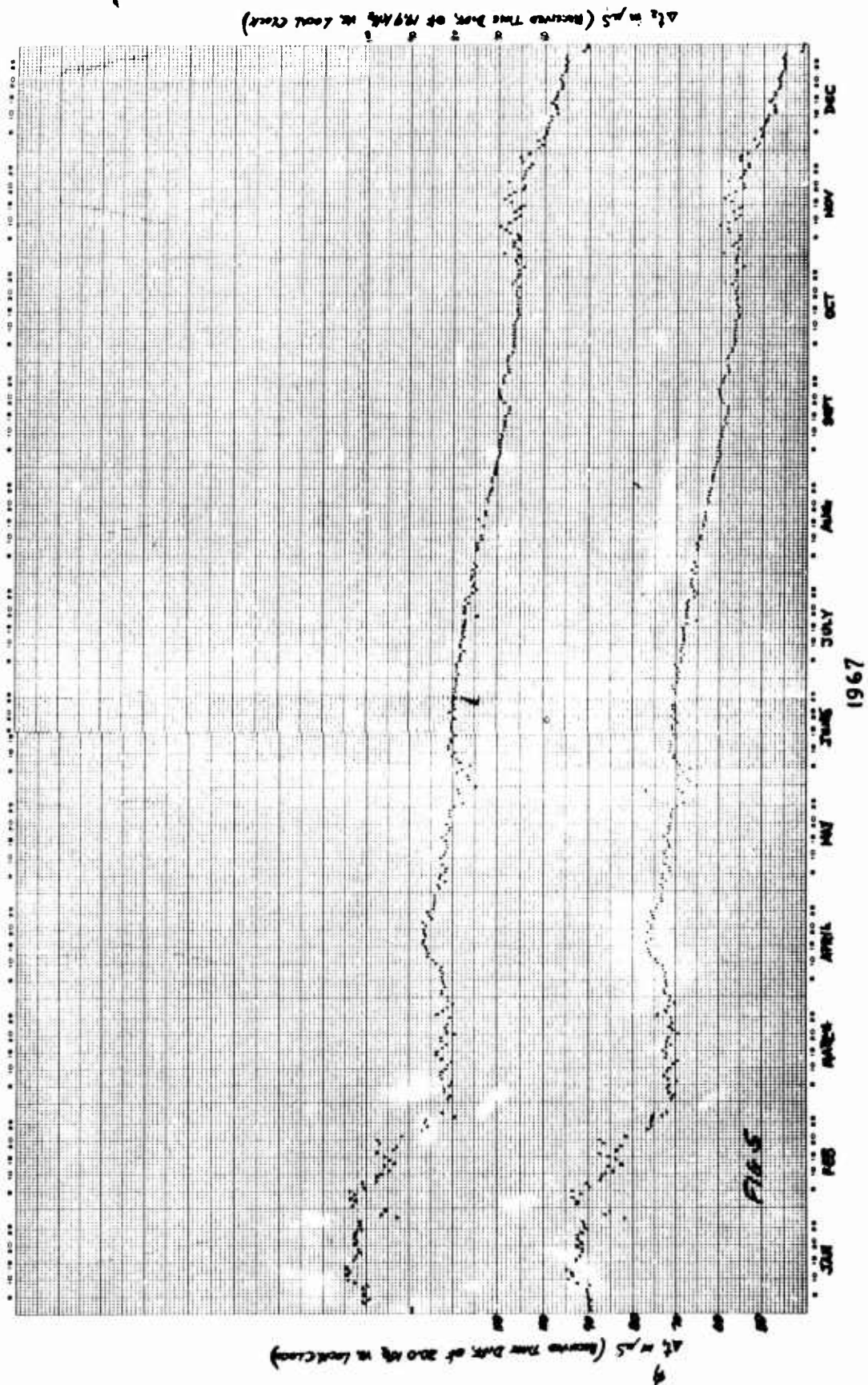
FIGURE 3

NOT REPRODUCIBLE



NOT REPRODUCIBLE

VLF DATA PLOT



## Precise Time and Time Interval (PTTI) Activities and Plans (USAF)

By

Mr. Ernest L. Kirkpatrick

Slide One serves to indicate the extent of interest in precise time and time interval at NAFS. The main point here is the fact that there are some ten people busy carrying time to some ten systems or about forty sites.

Slide Two indicates the composition of a redundant clock system for use at NAFS and other "Precise Time Reference Stations" (PTRS), three of which may be implemented at other Air Force stations this year.

Slide Three shows the three classifications of sites served by NAFS clock teams.

Slide Four shows the equipment proposed for service tests at some of the sites listed as Class III (Slide 3) and at some other Air Force precise measurement equipment laboratories (PMEL).



## NAFS SUPPORT INFORMATION

160 BASE LABORATORIES

6 AREA LABORATORIES

10 SYSTEMS

10 PERSONNEL

700 MAN-DAYS PER YEAR

40% TIME ON TDY

SLIDE 1

\$6,000 - MAXIMUM TICKET

27,000 MILES - MAXIMUM TRIP

\$400,000 - EQUIPMENT

\$450,000 - YEARLY TRANSPORTATION

## CLOCKS

HP 5060 A	2.0 CU. FT.	215 LBS.
HP 5061 A	1.5 CU. FT.	175 LBS.
HP 5065	1.5 CU. FT.	160 LBS.
TRACOR 307A	0.5 CU. FT.	31 LBS.
TRACOR 5A	0.5 CU. FT.	32 LBS.
TRACOR 1B	0.3 CU. FT.	15 LBS.

# U.S. AIR FORCE TIME STANDARD

RACK 4

DIGITAL ERROR MULTIPLIER
ELECTRONIC COUNTER
DIGITAL RECORDER
OSCILLOSCOPE W/CAMERA
MULTICOUPLER

RACK 5

LORAN C SYNCHRONIZER
LORAN C RECEIVER
OMEGA RECEIVER
W W V RECEIVER

RACK 3

DISTRIBUTION AMP.
COMPARATOR RECDR
VLF RECEIVER
CLOCK 3

RACK 2

DISTRIBUTION AMP.
COMPARATOR RECDR
VLF RECEIVER
CLOCK 2

RACK 1

DISTRIBUTION AMP.
COMPARATOR RECDR
VLF RECEIVER
CLOCK 1

SLIDE 2

# *P*RECISE *T*IME AND *T*IME *I*NTERVAL *C*ALIBRATION *S*UPPORT *P*LAN

## *C*ASS *I*.

*S*ITES LOCATED IN CLOSE PROXIMITY TO  
A CERTIFIED TIME REFERENCE STATION.

## *C*ASS *II*.

*S*ITES WITHIN GOOD RECEPTION RANGE OF  
CERTIFIED LORAN-C TRANSMITTERS THAT DO  
NOT QUALIFY FOR CLASS I.

## *C*ASS *III*.

*S*ITES THAT DO NOT QUALIFY FOR EITHER  
CLASS I OR CLASS II.

SLIDE 3

CRYSTAL CLOCK  
NO. 1

NEW HP  
OR  
SULZER 450

COMPARATOR  
RMS 9121

CRYSTAL CLOCK  
NO. 2

LORAN  
RECEIVER

AUSTRON 2000  
OR  
ARI LORCHRON

OMEGA  
RECEIVER

FLUKE 207-1 WITH  
291 AND 460

TIME INTERVAL  
COUNTER

HP 5275A

ERROR  
MULTIPLIER

ATEC 1011A  
OR  
RMS 9403

EQUIPMENT  
FOR KEEPING  
TIME

ASSOCIATED  
EQUIPMENT FOR  
OBTAINING AND  
MAINTAINING TIME

PROPOSED EQUIPMENT FOR  
PMEL SERVICE TESTS

(SLIDE 4)

## Open Discussion of Synchronization by Transportable Clocks

Conducted By

Mr. A. C. Schutheis

The Applied Physics Laboratory has conducted some experimentation in the transfer of time using crystal oscillators. It was shown that closure errors of 0.1 usec, with a 2.5 MHz crystal oscillator and .3 usec. with a 5.0 MHz crystal oscillator are achievable.

Stabilities of commercially available crystal oscillators such as Sulser are:

1 part in  $10^{-10}$  over 24 hours, and

1 part in  $10^{-11}$  over a 2-hour period

Measurement of a laboratory crystal oscillator against a Cesium Beam oscillator, shows a stability of:

5 parts in  $10^{-12}$  for 16 seconds, and

5 parts in  $10^{-12}$  for 160 seconds.

The cost of such a standard is approximately \$1500.00, weighs one pound, measures 3X5X10 inches including heater and oven.

## Use of Loran-C for Timing

By

Paul E. Pakos

Present Capability: Precise timing is presently available to any user within ground wave range (1000 miles) of any Loran-C station located in the following Loran-C Chains: U.S. East Coast, Norwegian Sea, Hawaiian, and Western Pacific. Since each slave of a chain is synchronized to its master to within  $\pm 0.2$  microsecond (3 sigma), this establishes the accuracy to which any number of user clocks can be set to each other, as long as they utilize Loran-C stations of the same chain. The attainment of such accuracy presumes that the user either knows precisely the propagation time from the station to his position, or he has been "calibrated" by a single visit of a portable clock. The user is additionally guaranteed that the transfer of time from Loran-C is presently held to  $\pm 25$  microseconds from UTC. Applying after-the-fact corrections published by the U.S. Naval Observatory results in at most, a 5 microsecond error with respect to UTC.

Future Capability: A tolerance of  $\pm 5$  in lieu of  $\pm 25$  microseconds from UTC can be applied immediately to the aforementioned Loran-C chains. It is no technical problem to reduce tolerance to  $\pm 1$  microsecond or better, but whether or not this will have an adverse impact on the navigational use of Loran-C must be resolved, and the control methods to accomplish this accuracy must be worked out. The remaining Loran-C chains

(North Atlantic, Mediterranean, Alaskan, Southeast Asia) could also be used to disseminate time if the requirement existed and funds were made available to the Coast Guard.

A recent development in the use of Loran-C skywaves has proven the ability to detect and utilize such signals at ranges of 8000 kilometers from the transmitting station. The stability of such signals must be investigated, but it is our expectation that a stability of three microseconds or better can be realized if the measurements are made at the same time each day, i. e., if propagation conditions are approximately the same. Use of Loran-C skywaves results in virtually world-wide coverage.

Operational Use of Loran-C for Timing: The accuracies presently available, the potential expansion of Loran-C timing coverage, and the low user cost (less than \$10,000) make Loran-C an attractive candidate as a source of precise timing information. However, the Coast Guard presently has no operational requirement to provide such services. As a result, timing is subordinated to the navigational use of the system and timing users are presently not warned when the transmissions are unreliable. A joint agreement, between those who levy the navigational requirements on the Coast Guard Loran-C system and those who desire the system to be declared operational for timing, is essential to resolve these problems.

# **EXISTING CAPABILITY OF LORAN-C FOR TIMING**





# CONDITIONS NECESSARY TO ACHIEVE

## AVAILABLE ACCURACY

1. USER POSITION KNOWN
2. PROPAGATION TIME KNOWN

## ALTERNATIVE:

CALIBRATE USER SYSTEM BY SINGLE VISIT  
OF PORTABLE CLOCK. REMOVES PREDICTION  
ERRORS AND ANY SYSTEMATIC ERRORS.

## **ACCURACY PRESENTLY AVAILABLE**

**A. WITHIN A SINGLE CHAIN:     $\pm 0.2$  MICROSEC**

**B. CHAIN TO CHAIN:             $\pm 25$  MICROSEC WITHOUT  
CORRECTION**

**$\pm 5$  MICROSEC AFTER  
NAV OBSY CORRECTION**

**USER COSTS FOR HIGH ACCURACY REQUIREMENTS**

1. RECEIVING ANTENNA SYSTEM	\$ 100
2. AUTOMATIC TIMING RECEIVER	\$ 5500
3. TIME INTERVAL COUNTER	\$ 2000
	<hr/>
TOTAL	\$ 7600

**POTENTIAL CAPABILITY  
OF LORAN - C FOR TIMING**



# POTENTIAL GROUNDWAVE TIMING ACCURACY

## FROM CHAIN TO CHAIN

A. IMMEDIATE IMPROVEMENT:

$\pm 5$  MICROSEC  
WITHOUT CORRECTION

B. FUTURE IMPROVEMENT:

$\pm 1$  MICROSEC OR  
BETTER WITHOUT  
CORRECTION IS  
FEASIBLE. IMPACT ON  
NAV SYSTEM MUST  
BE STUDIED

## **TIMING ACCURACY USING SKYWAVES**

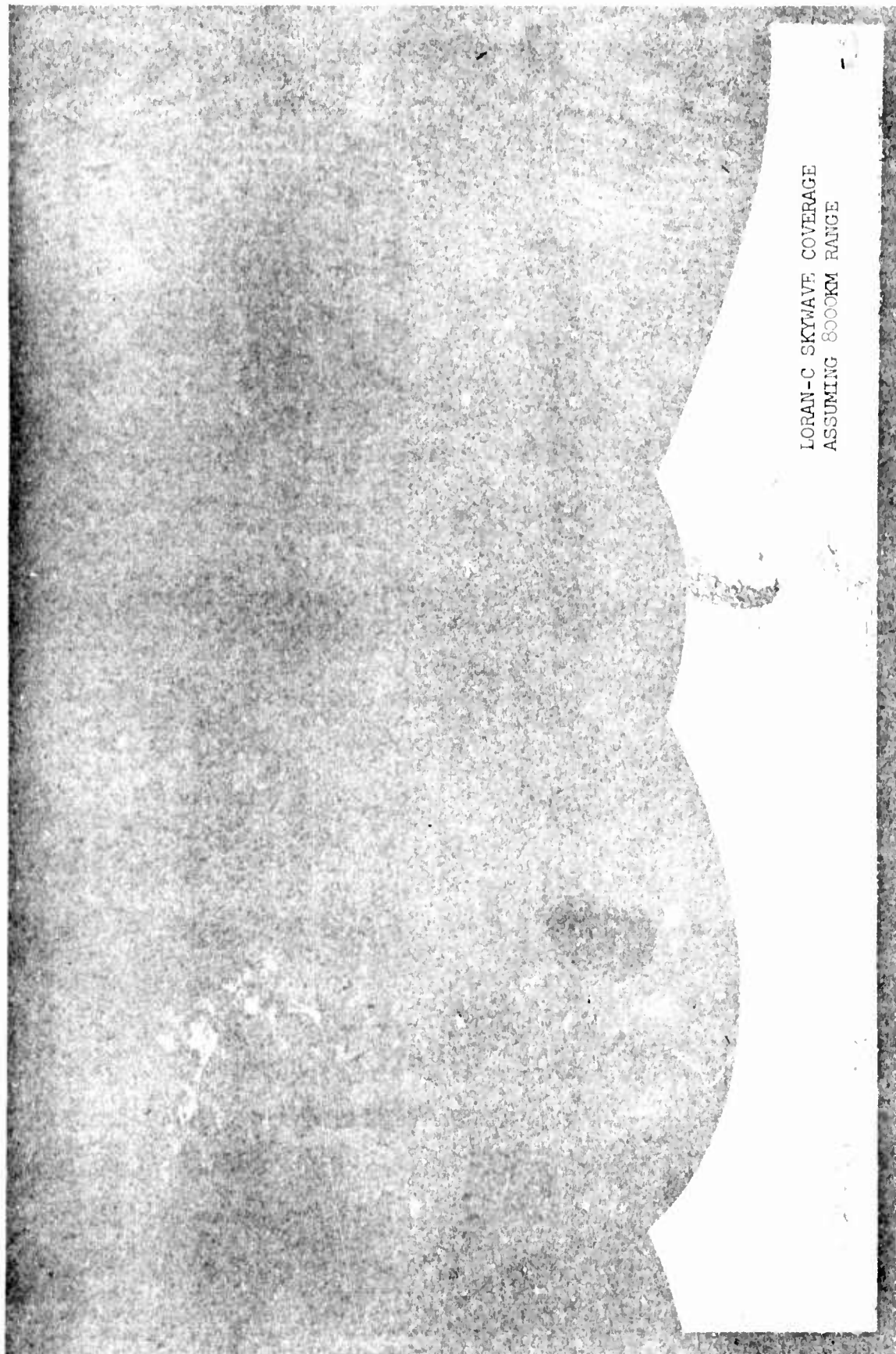
### **1. SKYWAVE RANGES:**

**8000 KILOMETERS DEMONSTRATED**

### **2. ACCURACY:**

**BETTER THAN 3 MICROSECONDS ON A RELATIVE BASIS. REQUIRES INITIAL CALIBRATION OF USER AND MEASUREMENT OF SKYWAVES AT SAME TIME EACH DAY. MORE DATA REQUIRED TO EXPLORE FULL POTENTIAL.**





## TIMING POTENTIAL OF LORAN-C/D

By

Dr. Bernard Wieder

Two factors must be considered when radio waves are to be used in synchronizing remote clocks. One is the predictability of the time required for the signals to get from the master clock to a slave clock; the other is the repeatability of the signal. Since the time of propagation is usually determined through a phase measurement, we are, in essence, talking about the predictability and repeatability of the phase of the signal at the location of the slave clocks. This is exactly the information required for precise navigation using the Loran-C/D system. In Loran-D, since the system is designed to be transportable and, therefore, not readily calibrated, the repeatability of position determination (through phase measurement of Loran-D signals) is paramount and the predictability is of only secondary importance.

For time synchronization of remotely located clocks, the same criteria should apply. Once a slave clock is initially calibrated (through a portable clock comparison), the paramount question is how accurately can the synchronism be maintained using Loran signals. Loran C/D has excellent performance in connection with the latter function. Predictability (i. e. , absolute calibration) is not nearly so good except under special circumstances.

Table I lists the factors that enter both the predictability and repeatability of Loran signals.

TABLE I

1. Equipment (Stability & Reliability)
2. Geometry
3. Interference
4. Propagation Considerations
  - a) Signal-to-noise ratio
  - b) Refractivity of the earth's atmosphere and its lapse rate
  - c) Earth conductivity and dielectric constant
  - d) Terrain irregularities
  - e) Skywaves

Discussion of equipment stability and reliability is beyond the scope of the presentation. It is a factor that is common to all timing systems.

For absolute time calibration, the delay of the signal through the equipment must be known; for repeatability, this delay must be maintained to close tolerance. Fortunately, this is not a particularly difficult problem. With good design and proper care, equipment stability can be maintained to about 0.1  $\mu$ s.

The geometry of the system plays an important role in the navigation problem where the accuracy of a position fix can depend on crossing angles of lines of position. For the timing problem, geometry is not

too important since a good survey can pinpoint the position of a timing installation with more than adequate accuracy, and it does not enter at all into the stability of the timing system.

The phase coding incorporated into the Loran system is designed to minimize interference. By appropriate decoding of the Loran signals, both synchronous and nonsynchronous interference can be minimized; and while the interference can produce instantaneous excursions in the timing synchronization signals of several tenths of a microsecond if the slave clock is adjusted on the basis of long-term averages, no serious problem results. This approach assumes, however, that the oscillator at the slave timing installation is of sufficiently high quality that only infrequent adjustments are required to keep it in synchronism with the master clock.

Finally, the actual propagation of the timing signals from master clock to slave clock enters into the equation. At our present stage of knowledge the propagation considerations severely limit the predictability of the Loran system, particularly for overland paths if microsecond or sub-microsecond synchronization is the requirement. On the other hand, the repeatability, which is required to maintain synchronization, suffers from adverse propagation effects in only a minor way.

Poor signal to noise ratio produces instantaneous errors in the synchronization signals. The comments above relating to interference are appropriate here. If the slave clock contains a high quality oscillator

so that it is only weakly coupled to the synchronization signals, the effect of noise in the system can be minimized. The refractivity of the atmosphere together with the atmospheric lapse rate partially determines the propagation time of the synchronizing signals. This effect is small although minor phase changes due to changes in the weather can be detected in systems capable of sub-microsecond accuracies.

Items c) and d) are the two major factors in limiting the predictability of the propagation time but play no essential role in the stability of the signal excepting insofar as the electrical parameters of the earth may vary with season, weather, moisture content, ground cover, etc. For over-water paths where the conductivity and dielectric constant of sea water is well established and the surface conforms closely to the smooth earth approximation that goes into the theory, our ability to predict propagation time is excellent -  $0.1 \mu s$  is readily obtainable. Over land, however, with only limited information available on earth conductivities, and where terrain irregularities can produce serious phase perturbations, predictability suffers. Measurements made during the late 1950's indicate that differences of as much as  $\pm 2.5 \mu s$  can exist between predicted and measured propagation times. We are currently involved in a program that will, hopefully, give improved predictions.

Finally, skywave contamination of the ground wave signals can produce phase errors. This can occur in two ways:

- 1) Sampling too high on the Loran pulses so that skywave component is present, and
- 2) Skywaves from preceding pulses overlapping on succeeding ground wave pulses.

The former is handled routinely and seems to give no difficulty in a reasonably good signal-to-noise environment. The latter can be considered as a special type of interference and the Loran coding scheme is specifically designed to minimize the errors due to this effect. In the presence of other types of interference, however, some compromise decoding format may be required. Further, for proper skywave suppression, there must not be any systematic changes in the skywave signals as might occur, for example, during sunrise and sunset.

In the amine, most of the propagation effects produce instantaneous variations that can be as much as  $0.2 \mu\text{s}$  ( $1\sigma$  value). By appropriate averaging, many of the variations are eliminated. For example, Loran monitor stations, using 15-minute averages report stabilities of about  $0.5 \mu\text{s}$  ( $1\sigma$  values). For timing systems in which the slave clocks have high stability so that infrequent adjustments are required to maintain synchronization, the Loran-C system can maintain sub-microsecond accuracies. However, the initial calibration of the remote clocks should be accomplished through portable cesium clocks or other precise clock comparison techniques.

## Navy Time/Frequency Programs

By

Martin Pozesky

- (1) Much of the advanced development work underway in the Navy is for electronic systems in support of the operational needs shown on this viewgraph - Communication, Navigation, Ident, C/C, ATC/L, ECM/ECCM, and Detection.
- (2) Historically, as one views the various requirements characteristic of the evolutionary growth of electronic systems, one can see requirements for more accurate this; increased that. Today, the various systems being developed for the 1972 - 1978 time period are required to have improved accuracy, increased range, security and all it connotes. These systems must serve increasing numbers of uses, make more efficient use of the RF spectrum, provided increased operational reliability (not just increased MTBF but decreased MTTR, improved support, etc.) and finally provide increasing numbers of functions.

As one takes a look at these increased system capabilities/requirements, it can be seen that time/frequency techniques offer the potential of enabling all these increases in operational parameters.

Improved accuracy is inherent. Increased range can be obtained because you now know when and where to look for the signal; thus narrower bandwidth, higher sensitivity receivers can be utilized.

Security through the use of time/frequency diversity techniques is well known. One-way transmission allows you to serve more users and (together with accurate frequency control) provides more efficient use of the spectrum.

Using closely controlled time sharing, one-way transmission for range, doppler frequency measurements, etc., can provide multiple system functions.

- (3) This next chart illustrates the extent of the Navy's involvement in the systems.

As we all know the Navy is the DOD executive agent to provide time and frequency service to all DOD agencies (Naval Observatory). However, in addition to this function the Navy has in operation two (2) Navigation Systems based upon accurate control of time/frequency. Two other systems are presently being implemented. A total of twelve systems based on T/F are presently being developed; and at the time of preparation of this chart, I know of two additional systems being proposed.

Recently, and fortunately, the Navy fell back, regrouped, and took stock of its rapidly increasing involvement in T/F techniques. As of about one year ago, the path being taken for all of these systems and developments was to procure its own frequency standard and provide synchronization inherent to each system.



It became obvious that one day some airplane would wind up with three or four frequency standards, each peculiar to a particular system, and each system was going to have its own peculiar synchronization techniques. A lot of tax dollars would be wasted.

Faced with this dilemma, the Navy decided to develop a single frequency standard applicable to all envisioned systems and a synchronization network independent of any single system. Thus, as various systems are developed, they would be subscribers to this T/F network.

- (4) Toward this end, the Navy established the TACTAFS (Tactical Time and Frequency Service) Program. TACTAFS is chartered with the responsibility to:

(1) Develop standard ( $1 \times 10^{-11}$ ) for use in aircraft, ships, and on shore.

(2) Develop and implement the required frequency/time distribution system to make this information available to various users on ship or shore.

(3) Provide required synchronization system.

Because of the context of the conference today, I will address myself primarily to the problems of synchronization.

- (5) The synchronization problems may be divided into three general areas. The first - tactical - are for missions in a limited geographic area (such as Viet Nam) where requirements for tactical and air traffic

control synchronization can be provided on a mission by mission basis to a relatively small number of users.

The second, which I have called continental, addresses problems of synchronization over extremely large land masses (such as CONUS). Here, requirements are mainly for ATC purposes although tactical users are certainly possible. Synchronization requirements in this region are of a continuous, year-around nature.

The last, and most encompassing, is the continuous world-wide synchronization problem. To attack this total scope, it would be nice if we could start with world-wide synchronization and work inward. However, as is most often the case, we must go the other way.

- (6) This viewgraph shows in pictorial form what we now envision as the very basic synchronization philosophy.

Within the tactical or area environment, one ship will be designated as primary standard within a task force. Synchronization to other ships will be accomplished only on flight deck prior to launch. Once the aircraft leaves the carrier, no ship to air synchronization will take place. The inherent stability of the clock will be such as to be within the required using system tolerances over a four-hour mission time. However, if required for some subscribing system, capability will be provided for A/A synchronization via two-way data link.

Continental synchronization will be accomplished by use of an extensive network of ground update stations. These stations will be

calibrated by jurisdictional shipyards or NAS, either by calibration teams or data link relay. The ship standard will be calibrated by area centers traceable to the Naval Observatory.

At the present time extensive use of time hierarchy techniques in this environment is not envisioned.

Finally, in the world-wide mode, system synchronization is presently envisioned by utilizing the Navy's Omega navigation system or through the use of satellites, either of which are directly traceable to the Naval Observatory. Whether or not that dotted line connecting the aircraft with the satellites or Omega becomes a solid, firm line will be a function of the operational feasibility/desirability of these systems for airborne vehicles.

- (7) In summary, the TACTAFS Program is divided into two phases. The first phase, labeled short term (although a misnomer), will attack the problem of tactical and continental synchronization. Initially, the oscillators envisioned for this time period will be cesium as the basic standard with very selective use of crystal clocks.

Distribution will be via what is called "disciplined crystal oscillators" at the termination end of coax cables. Synchronization will address the problem of DEUL/flight line synchronization/with the addition of synchronization capability to existing and planned data links.

The long-term program will address the further problem of development of cesium and rubidium clocks for tactical usage. The distribution

system is envisioned to be similar to that under the shorter term program. Synchronization will utilize those systems/equipment/techniques developed in the short term phase with the significant addition of world-wide synchronization via Omega or satellites.

Gentlemen, that concludes my presentation. I apologize for the lack of technical detail or detailed system parameters and tolerances. However, all of these numbers and details are classified and, thus, cannot be presented at this conference.

I thank you for your attention.

OPERATIONAL NEED

COMMUNICATION

IDENTIFICATION

NAVIGATION

COMMAND AND CONTROL

AIR TRAFFIC CONTROL/LANDING

ECM/ECCM

DETECTION

IMPROVED ACCURACY  
INCREASED RANGE  
SECURITY  
SERVE MORE USERS  
EFFICIENT USE OF SPECTRUM  
OPERATIONAL RELIABILITY  
MULTIPLE FUNCTIONS

**T/F DEPENDENT SYSTEMS**

**OPERATIONAL:**

Navigation (2)

**BEING IMPLEMENTED:**

Navigation (1)  
Communication (1)

**DEVELOPMENT:**

Communication (1)  
Navigation (2)  
Identification (2)  
Air Traffic Control/Landing (1)  
Command and Control (1)  
Detection (3)  
ECM/ECCM (2)

**PROPOSED/EXPLORATORY DEVELOPMENT:**

Integrated CNI (1)  
Integrated ATC/CAS/Landing (1)

## TACTAFS

### TACTICAL TIME AND FREQUENCY SERVICE

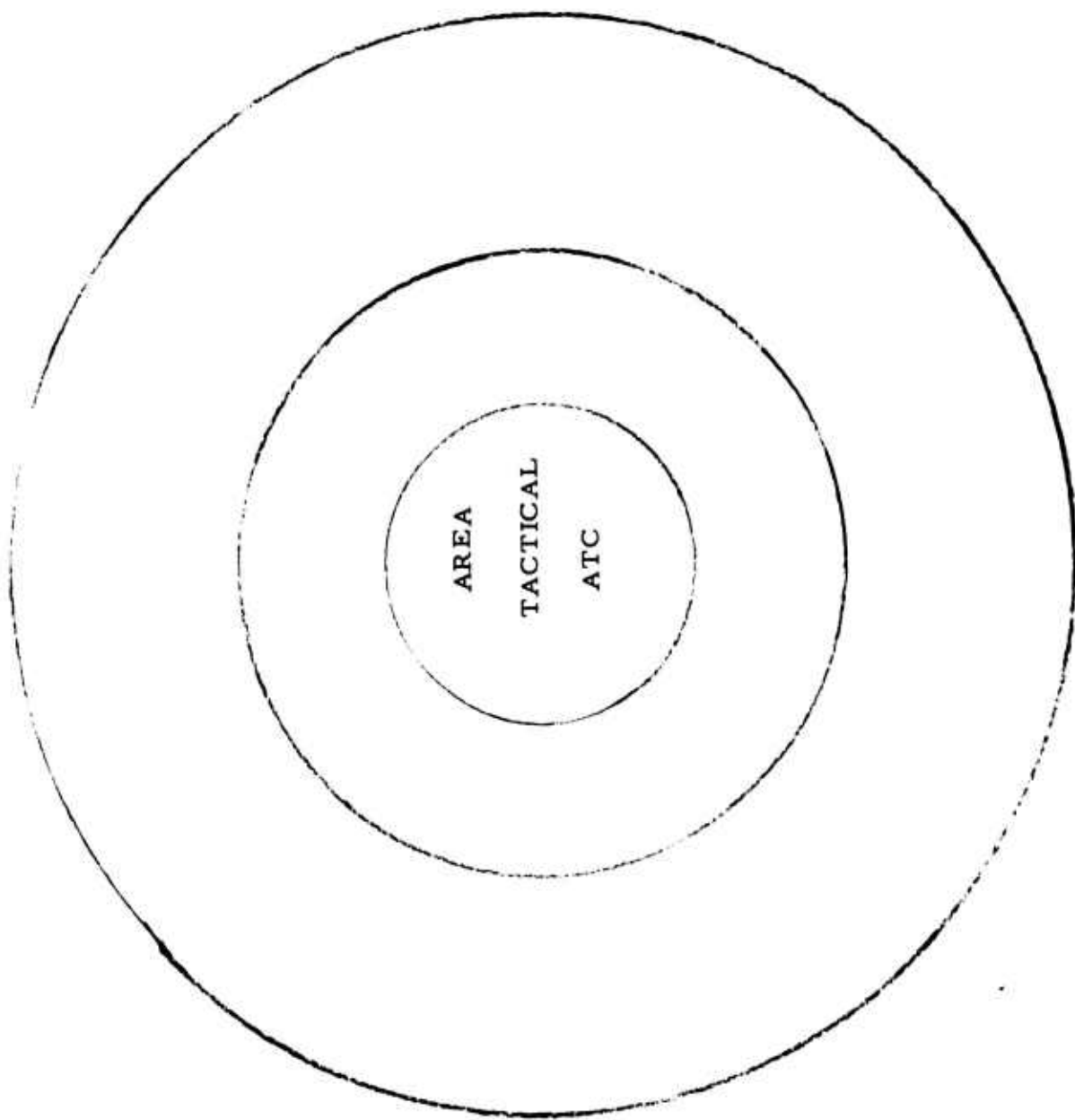
#### CHARTER

Develop and procure an atomic frequency standard ( $1 \times 10^{11}$ ) suitable for use in tactical aircraft, aboard ship, and on shore.

Develop and implement the necessary distribution systems to distribute this information to various users within the aircraft, ship, or shore station.

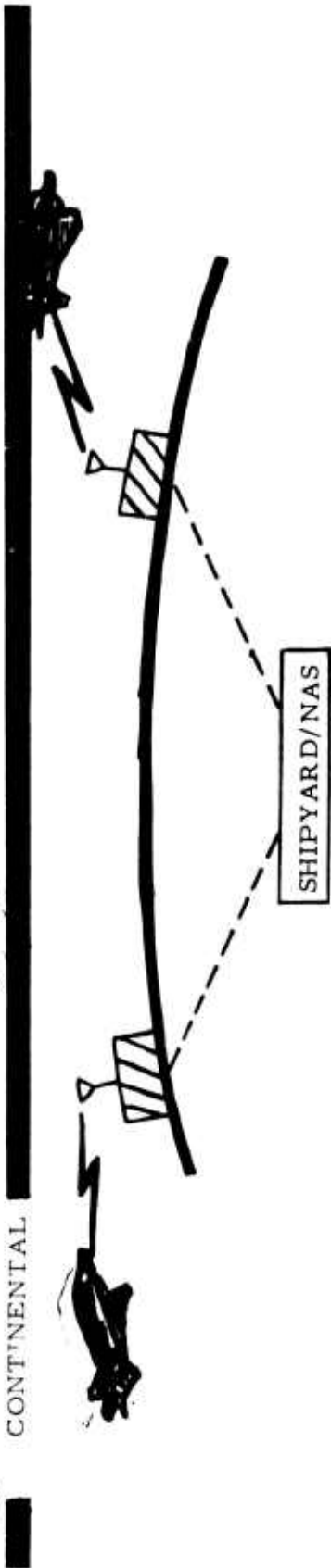
Develop and implement the required synchronization network to synchronize all users (one microsecond).



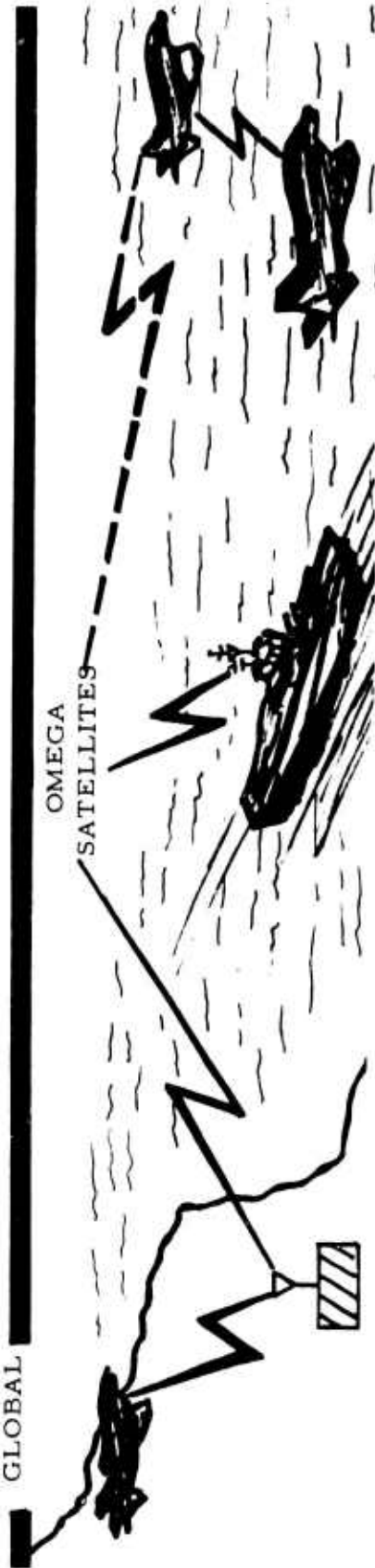




CONTINENTAL



GLOBAL



OMEGA  
SATELLITES

TACTAFS PROGRAM

SHORT TERM (CY 1969 - 1973)

Oscillator: Cesium, Crystal

Distribution: "Disciplined Crystal Oscillators"

Synchronization: Ground Beacon  
Air/Surface Relay Via Data Link

LONG TERM (CY 1969 - 1976)

Oscillator: Cesium, Rubidium

Distribution: "Disciplined Crystal Oscillators"

World-Wide Synchronization: Ground Beacon  
Air Relay Via Data Link  
Omega/Satellites

# APPLICATION OF TIME/FREQUENCY TECHNIQUES IN MILITARY STATIONKEEPING

by Robert L. Huff

Radio Navigation and Beacon Branch  
Aeronautical Systems Division ASNAG-10  
Wright-Patterson AFB, Dayton, Ohio

## INTRODUCTION

This discussion of time/frequency techniques will be limited to military applications involving stationkeeping. Late in 1963 after completion of a joint Air Force/Army field exercise called "Project Close Look", the Tactical Air Command issued an operational requirement for a system to permit close formation flying in bad weather and at night. Of the several solutions proposed by industry, one offered the one-way ranging concept using time/frequency techniques.

## MILITARY STATIONKEEPING APPLICATIONS OF TIME/FREQUENCY TECHNOLOGY

### One-Way Ranging

One-way ranging is possible through the use of precisely synchronized crystal oscillator clocks in each aircraft as a common time reference for extracting range information from the arrival time of pulsed R-F energy. Transmission of this energy is initiated by one local clock at one assigned time. If all clocks in the other aircraft in the formation are precisely aligned with the master clock, then all receiving stations know both the assigned transmission time and the measured arrival time of the pulsed R-F energy. Consequently, the propagation delay is known at all receiving stations, and therefore the range to the transmitting station.

Each station takes its turn at transmitting at a set time while all other stations are listening. The slant range is equal to the measured delay between transmitting and receiving stations multiplied by the propagation velocity.

Aside from use of local clocks as a time reference along with the need for precise synchronization, the time/frequency techniques also requires that a separate time slot be available for each aircraft in the formation. This involves a time-shared multiplex operation.

## The AN/APN-169 Stationkeeping System

One stationkeeping system being tested by the Air Force has a capability of operating 18 aircraft in a formation (C-130E) with a minimum separation of 2200 ft. in bad weather or at night. The specified range of the system is 10 nautical miles with full 360 degree coverage in azimuth. The required range measurement accuracy is  $\pm 200$  ft. and the azimuth accuracy is  $\pm 2$  degrees. These accuracies have been validated at the Eglin test range, both in regard to compliance of hardware performance with established Air Force requirements and to their need. Figure 1 gives an impression on the utilization of horizontal airspace compared with the alarm boundaries of the ATA defined civilian collision avoidance system (CAS) in random encounters of civilian aircraft.

### Integral Data Link

The Air Force stationkeeping system not only gives positional information on a PPI scope display but has another function - a data link which permits individual aircraft in the formation to announce turn maneuvers as well as exchange altitude information between aircraft such as altitude.

### R-F Carrier

Choice of the 3400 megahertz R-F carrier does permit full range operation in adverse weather with low peak power output. Even so the rotating directional antenna is 28 inches in diameter.

### Slot Identity

Each station takes its turn transmitting at an assigned time. The classical model for the illustration of this scheme translates the micro-second/nanosecond time scale of one-way ranging into the hour/minute scale of an everyday wristwatch. Assuming station No. 1 transmits a burst of R-F energy precisely at 1 p. m., station 2 at 2 p. m., etc. and assuming distances between all stations are less than one light hour, the following can be concluded:

(a) If the R-F pulsed energy arrives after 1:00 p. m., but before 2:00 p. m., it was transmitted by station 1. This establishes aircraft identity without additional transmissions of address codes.

### Multipath Suppression

Signals radiated from one station will ordinarily reach another station in a direct path, accompanied by forward scatter via multipaths. Multipath echoes arrive slightly later than the direct path signal. They may overlap the direct signal and also may lengthen it. They may overlap a successive pulse and produce a false leading edge for that pulse. The multipath must be suppressed and isolated in order to prevent erroneous information.

The APN-169 stationkeeper reduces effects of multipath by the following techniques:

- (1) The use of short-duration pulses for data transmission.
- (2) Leading edge detection.

A coded pulse group is decoded and stored in a delay line decoder. Only the leading edge of the first pulse of the code group is then used for range information and all other pulses are suppressed.

- (3) Antenna directivity (6 degree beamwidth)
- (4) Amplitude discrimination by means of stored-slot AGC.

## FLIGHT EVALUATIONS

### Air Force

The first practical demonstration of time/frequency techniques in a stationkeeping application by the Air Force was made in late 1964 at Buffalo International Airport. Accuracy measurements were made at the Eglin Air Proving Ground Center, Florida. The Sierra Research Corporation of Buffalo, New York built 3 systems and installed them in 3 C-130E transport aircraft. The equipment was further used and flight tested in actual tactical military operations in the continental U. S. and Canada, and during an airlift to a Caribbean island.

Flight operations included IFR formation flight assault landings, low level formation flights, and heavy equipment drops. In addition, one system was placed on the ground to demonstrate its use as a ground marker beacon. ILS and GCA formation landings under IFR conditions were accomplished

using the Sierra stationkeeping equipment. The Tactical Air Command under an AFLC contract with Sierra is presently installing sixteen systems in sixteen C-130E aircraft for further testing at Pope AFB and in an operational environment. The nomenclature for this equipment is "Intraformation Positioning Set, AN/APN-169". I did not pick this title, incidentally.

The Air Force has demonstrated in many flight operations that reliable air-to-air synchronization is practical in flights down to the ground. The AN/APN-169 system was found to provide "collision protection" within the formation while performing tactical air assault maneuvers during night or bad weather conditions, in addition to capability of delivering supplies to a forward area at 5 second intervals using low-level in-trail techniques. Lockheed will also supply stationkeeping equipment in the C-5A aircraft also employing time/frequency, one-way ranging techniques. It will be fully tested in C-5A aircraft early in 1969.

#### Army

In April 1965, at the request of the Advanced Research Projects Agency (DOD), the Army installed 3 Sierra stationkeeping systems in 3 Army helicopters for evaluation and application to Army helicopter operations. Although accuracy measurements made by the Army were within required design limits, it was found that the helicopter needs a higher data rate because of the closer formation spacing required in helicopter operations. Also, the equipment must be made smaller than that used in a transport aircraft.

As was expected the synchronized time slot multiplex operation has proven itself free from the mutual interference which would otherwise occur among many stations operating on the same frequency and in close proximity.

## THREAT SENSING CRITERIA

### General

In discussing collision threat criteria we should consider the following parameters:

Proximity (Slant Range)

$$\text{Tau} = \frac{\text{Range}}{\text{Closing Velocity (Range Rate)}} = \text{time to collision}$$

Relative Altitude

Bearing

Heading (other aircraft's)

Maneuver Intent

Identification

The APN-169 (Sierra Research) system has all parameters available except Tau. This could be provided, if required but with some additional design work. The ATA CAS design does not call for bearing information or maneuver intent.

It is rather evident that the systems for military service operations (requiring close formation flying) emphasize proximity and bearing parameters, while civilian users (with random encounters of aircraft in large airspace) have emphasized the Tau and altitude parameters.

### Altitude

Altitude separation between aircraft is a prime factor of interest; if aircraft are not now at the same altitude nor will be in the immediate future, there is no need to further evaluate the situation for a possible collision threat.

### Bearing

When aircraft in formation must ordinarily fly closer than 1.5 nautical miles to each other, bearing information must be obtained by conventional means for better utilization of airspace. This has the practical disadvantage of requiring a directional rotating antenna of rather large dimensions, depending on the carrier frequency chosen. This often prevents its usage on smaller aircraft.



### Maneuver Intent and Identification

Those two bits of data are also useful in collision evaluation criteria in close formation flying. The APN-169, because of its data link capability, can transmit intended maneuvers and identification of other aircraft in a formation.

### Vertical Maneuvers

The McDonnell-Douglas EROS System and the ATA CAS system have no bearing information available that would allow avoidance maneuvers in the horizontal plane. They therefore depend on vertical climb and descent avoidance maneuvers. The aircraft on a collision course are commanded to execute climb and descent maneuvers to correct the collision hazard.

### Horizontal Maneuvers

An entirely different hazard philosophy, avoidance maneuver concept, and display requirement apply in military close formation ordered situation. Perhaps the formation flying stationkeeping approach may some day find application to holding patterns around busy airports, if the increase in air traffic continues.

Whenever a military aircraft changes its assigned position relative to others in a close formation, the danger of a collision is immediately present. The pilot cannot depend on collision warning boundaries such as in the civilian collision avoidance system. He cannot wait until his CAS determines whether this boundary of protection actually impinges on someone else's; he already flies too close for this. In other words, Air Force transport aircraft, flying in routine formation, would have climb or dive avoidance maneuver commands displayed all the time. In contrast, the pilot of a civilian aircraft can maneuver in air space with much less restraint than a military pilot flying in formation.

In the military case, the purpose of the avoidance maneuver is to bring the aircraft back exactly to its assigned position in the formation rather than just get it out of the way by moving to a different altitude.

## Displays

In most cases, the military pilot needs a display to tell him his position relative to other aircraft in the formation. In the case of the Air Force and Navy this takes the form of a PPI or radar scope. Sometimes an auxiliary digital readout is used for tracking an aircraft immediately in front. This instrument will generally read range more accurately than a scope type of display.

## CONCLUSION

By the use of time/frequency stationkeeping, collision avoidance protection has been provided among aircraft that ordinarily fly much closer than civilian aircraft. The Air Force has developed this stationkeeping system through four generations of hardware and through many flight tests under realistic operational conditions. As a result, there has been a growing acceptance of the techniques for one-way ranging, air-to-air clock alignment, and synchronized time slot multiplexing as the best solutions not only for airborne stationkeeping in military formation flying but also in collision avoidance, random encounters of civilian aircraft.

What will the future bring in airborne military applications of time/frequency techniques? Are we heading for an integration of the existing Air Force stationkeeping system with the civilian collision avoidance system now being developed?

It would be unrealistic to assume that a simple addition of the range rate computation would convert the Air Force stationkeeping system into the collision avoidance system wanted by the airlines. It would be equally unrealistic to assume that the addition of an L-band directional antenna system to the ATA defined collision avoidance system would enable it to meet the established Air Force requirements.

The Air Force pilot must precisely maintain his position relative to the other aircraft in the formation. This requires accurate bearing measurements, and therefore operation at a much higher R-F carrier frequency. Vertical avoidance maneuvers are impossible in military tree-top level flying. A different display philosophy applies and the pilot's decision making ability is utilized to cope with combat situations where the plans of men and the programming of computers need to change.

There is, however, little doubt that at some future time the two systems can assist each other for better overall function and it may then be desirable to put them in a common set of black boxes to minimize duplication of circuitry. Sierra Research, the supplier of the AN/APN-169, has for instance, worked out a method whereby a TACAN ground installation may be utilized in a temporary back-up mode operation to facilitate stationkeeping clock alignment to each other of two flight formations that are not in stationkeeping radio contact with each other. Once CAS synchronization signals become available world-wide, it would be a logical next step to investigate whether the CAS message could become the master timing function for stationkeeping of all flight formations wherever they are. Sierra tells me that it may even be possible to retrofit collision avoidance systems and a master timing coupler into Air Force aircraft already equipped with stationkeeping equipment of the present established Air Force configuration.

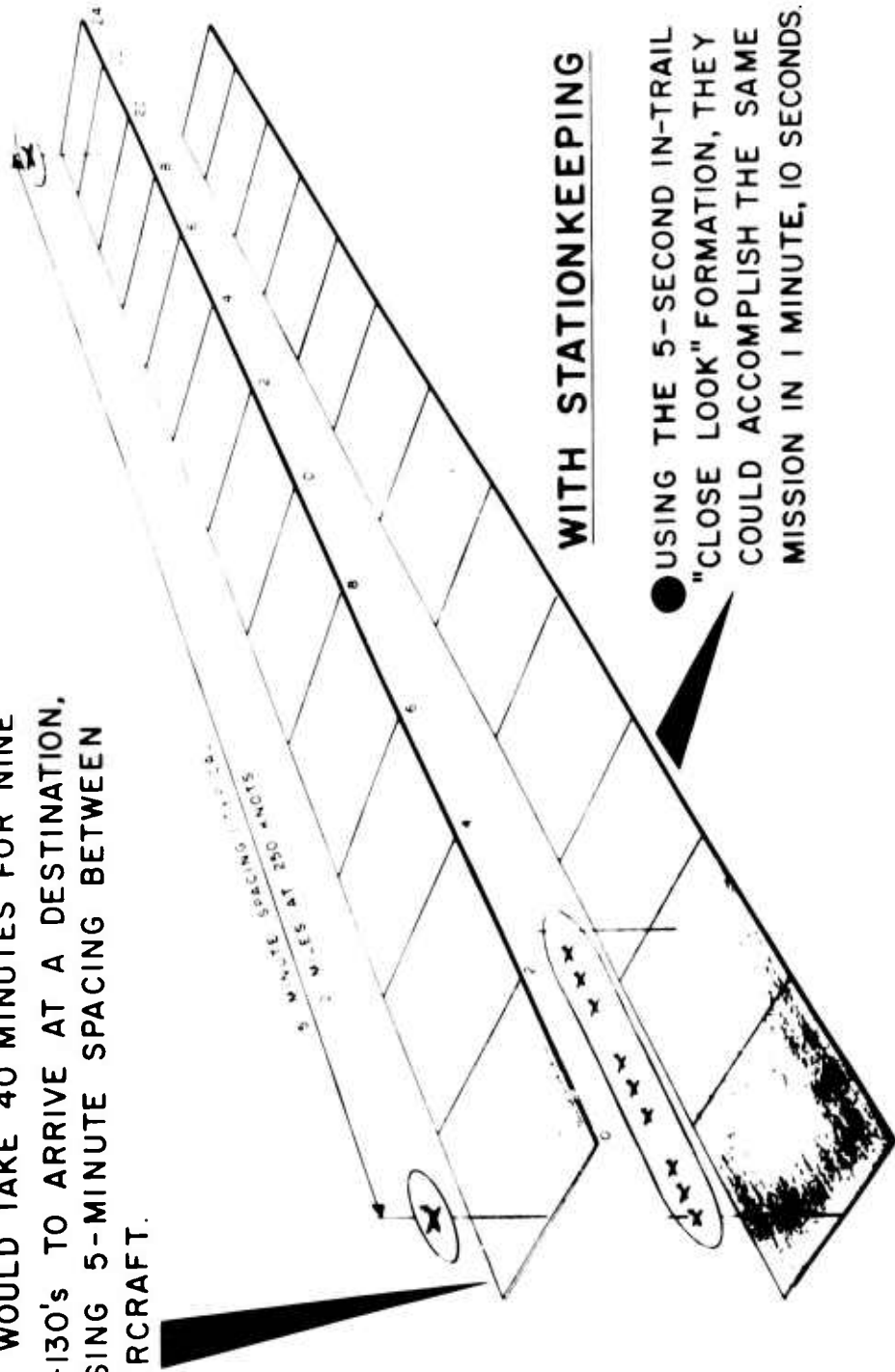
# IFR FORMATION MISSIONS

## WITHOUT STATIONKEEPING

- IT WOULD TAKE 40 MINUTES FOR NINE C-130's TO ARRIVE AT A DESTINATION, USING 5-MINUTE SPACING BETWEEN AIRCRAFT.

## WITH STATIONKEEPING

- USING THE 5-SECOND IN-TRAIL "CLOSE LOOK" FORMATION, THEY COULD ACCOMPLISH THE SAME MISSION IN 1 MINUTE, 10 SECONDS.



# FEASIBILITY FLIGHT TEST RESULTS

<u>PARAMETER</u>	<u>REQUIREMENT</u>	<u>RESULTS</u>
<u>AZIMUTH</u>		
COVERAGE ACCURACY	360° ± 2°	360° ± 2°
<u>ELEVATION</u>		
COVERAGE TO ACT AS A GROUND BEACON	± 15° NONE	± 15° SUCCESSFULLY DEMONSTRATED
<u>RANGE</u>		
CLOSE RANGE LONG RANGE RANGE ACCURACY	200 FT 10 NAUTICAL MILES 200 FT OR 5% OF DISTANCE, WHICH EVER IS MORE	LESS THAN 200 FT AT LEAST 10 N. M. ACCURACY GREATER THAN MINIMUM REQUIREMENTS



**PROGRAM FOR INTRODUCTION OF AIR-TO-AIR  
INTO USAF AIRLIFT AIRCRAFT**

**PROPOSED PRODUCTION AN/APN-169**

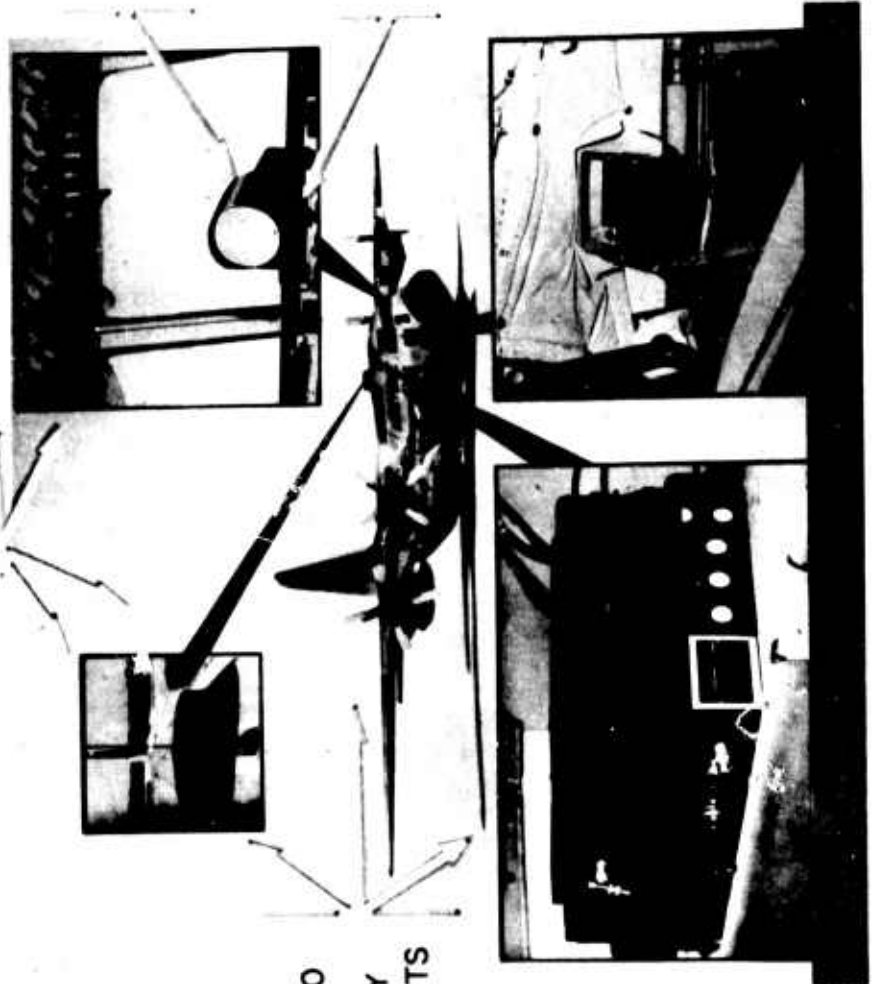
16 AIRCRAFT  
INSTEAD OF 12

BUILT-IN  
TESTING

LOW  
PROFILE  
INDICATOR

EVENT  
TELEMETRY

MIL-E 5400  
RELIABILITY  
IMPROVEMENTS





# THREAT SENSING CRITERIA

PROXIMITY	Δ
$\text{Tau} = \frac{\text{RANGE}}{\text{RANGE RATE}} = \text{TIME TO COLLISION}$	*
CO-ALTITUDE	* Δ
BEARING	Δ
HEADING (OTHER AIRCRAFTS')	Δ
MANEUVER INTENT	* Δ
AIR SPEED	Δ
IDENTIFICATION	Δ
* COLLISION AVOIDANCE PARAMETERS	
Δ STATION KEEPING PARAMETERS	

U.S.A.F. FLIGHT  
FORMATION  
(CLOSE LOOK)

CIVILIAN COLLISION AVOIDANCE  
(ATA)

NAUT.  
MILES

7

6

5

4

3

2

1

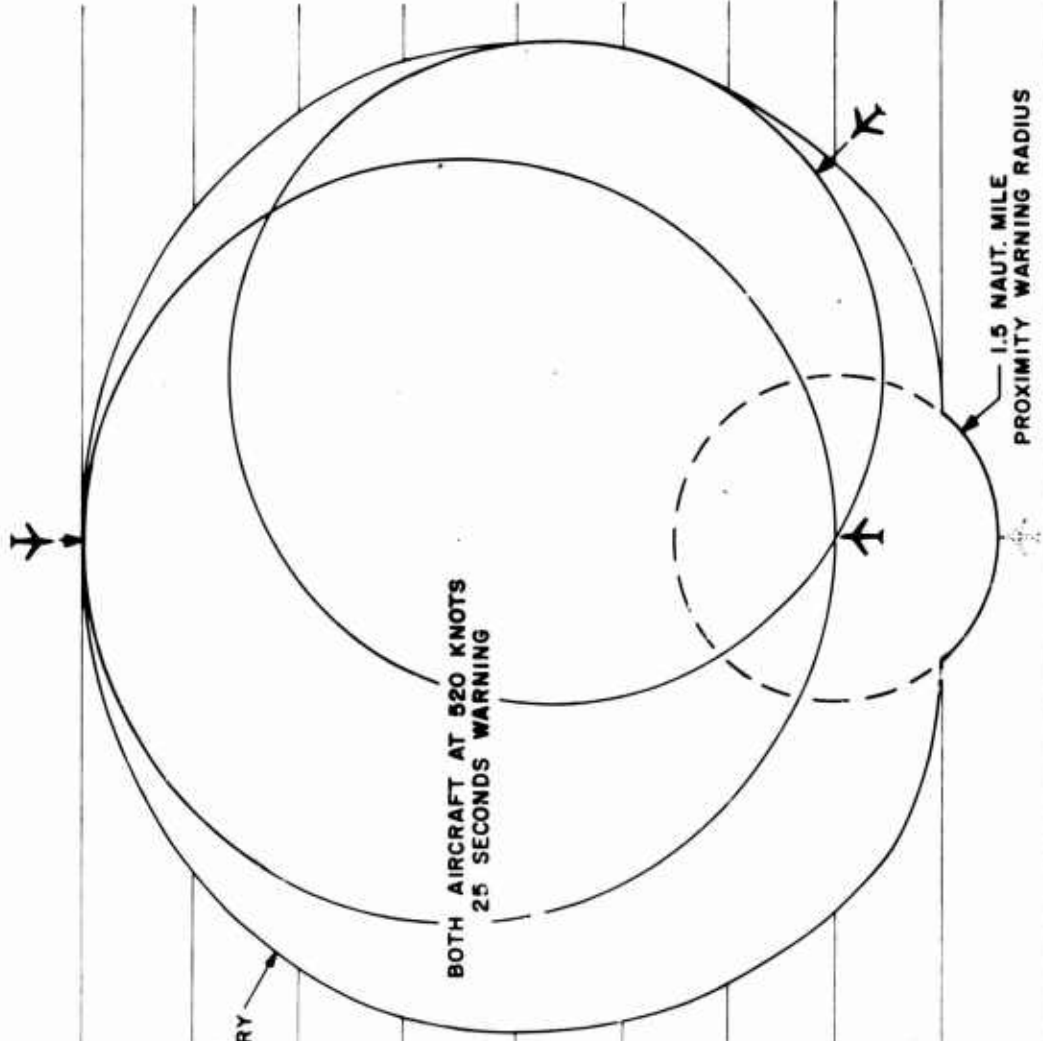
0

-1

-2



TAU COLLISION  
WARNING BOUNDARY



BOTH AIRCRAFT AT 520 KNOTS  
25 SECONDS WARNING

1.5 NAUT. MILE  
PROXIMITY WARNING RADIUS



## Time Dissemination by Satellite

By

G. C. Weiffenbach  
John Hopkins University  
Applied Physics Laboratory

The major advantage of using satellites for time dissemination is the ability to use line-of-sight radio frequencies to cover very large geographic areas.

Wide geographic coverage can be gotten in surface to surface communication only by using the ionosphere to obtain ducting or reflection to propagate around the curvature of the earth. Thus, of necessity, one must use radio frequencies which interact strongly with the ionosphere and which are subject to multipath problems. The resulting uncertainties in propagation are a fundamental obstacle to the attainment of synchronization to better than a few microseconds at ranges beyond several hundred miles.

Two kinds of satellite orbits are of particular interest for time dissemination: high altitude (22,000 miles) synchronous orbits which are simultaneously visible over intercontinental distances, and low altitude (e.g., 600 miles) polar orbits, in which a single satellite is visible from all points on the earth at some time within every 12 hour interval by virtue of the orbital motion of the satellite and the rotation of the earth under the orbit. In both cases it is possible to reduce propagation time uncertainties to the level of 10 nanoseconds.

The Navy Navigational Satellite System (TRANSIT) has been used to disseminate time to both navigators and a global network of tracking stations (TRANET) on an operational basis for several years. TRANSIT uses four satellites in 600 nm polar orbits to provide full global coverage. The time synchronization accuracy requirement of 400 microseconds has been maintained continuously since TRANSIT was first declared operational in 1964, the timing error typically being held to better than 100 microseconds RMS.

Each operational TRANSIT satellite carries an ultra-stable crystal oscillator with a drift rate of 5 to 10 parts in  $10^{11}$  per day. These oscillators are required for maintaining stable transmissions on 150 and 400 MHz for making doppler measurements for both tracking and navigation. Clearly they can also serve as clocks and are so used by means of divider chains which provide time markers every even integer UTC minute. These time markers are impressed on the doppler carriers so they can be received by the same equipment which is used for tracking or navigating.

The TRANSIT tracking stations routinely observe these time markers at the same time that doppler measurements are made. The doppler data are used to obtain the satellite transmitter frequencies which are directly related to clock rate. This information is then used to adjust satellite clock epoch and rate by ground command.

For accurate time recovery, one must know the range to the satellite at the instant a time marker is broadcast from the satellite. In the TRANSIT this information is also needed for navigation, so a fresh ephemeris is computed daily for each operational satellite. These ephemerides are transmitted to the appropriate satellite for storage in on-board memories. Each TRANSIT satellite then continuously broadcasts its own position for each even integer minute. The range uncertainties caused by inaccuracies in satellite position are typically equivalent to timing errors of the order of 50 nanoseconds.

The present timing accuracy in TRANSIT is substantially poorer than what is needed for a Time/Frequency Collision Avoidance System. It must be emphasized, however, that there are no fundamental obstacles to upgrading TRANSIT to meet the stated CAS requirement of 125 nanoseconds RMS. The principal modifications needed to obtain this increase in timing accuracy are the addition of a higher modulating frequency for the time markers and the use of a Rubidium Vapor frequency standard in the satellites. Both modifications are now technically feasible.

Raising the modulation frequency will increase the resolution of each time measurement. The present frequency of 400 Hz restricts the time decoding resolution to about 10 microseconds (about 1 degree of phase). It is possible to superimpose a modulation of about 25 KHz on the present bit pattern without disturbing existing equipment. This would result in resolution of the order of 40 nanoseconds for each measurement.

The use of the Rb standard (which would also enhance navigation accuracy) would result in more accurate prediction of clock rate. The drift of Rb standards can be predicted ahead for 24 hours to an accuracy of a few parts in  $10^{13}$ , which would produce errors of less than 50 nanoseconds.

Important advantages result from redundancy when using TRANSIT for global time synchronization. First, accuracy will be enhanced by data averaging. About 6 measurements can be gotten for each pass, and 5 or 6 passes can be gotten each day for each of the four satellites. Random measuring errors clearly will be reduced by averaging. But even ephemeris errors, which are systematic for each satellite pass, tend not to be correlated from pass to pass and satellite to satellite, and so they will also be reduced.

The fact that each satellite can be observed at every site, including a designated "master" station, several times each day avoids the accumulation of error that is possible in a system in which timing is transmitted serially from one point to another. Finally, reliability is enhanced by the observation at each site of 4 independent satellite clocks.

## REMARKS ON FREQUENCY COMBINER

### AND MICROELECTRONIC CLOCK

M. E. Shawe, Code 521

NASA, Goddard Space Flight Center

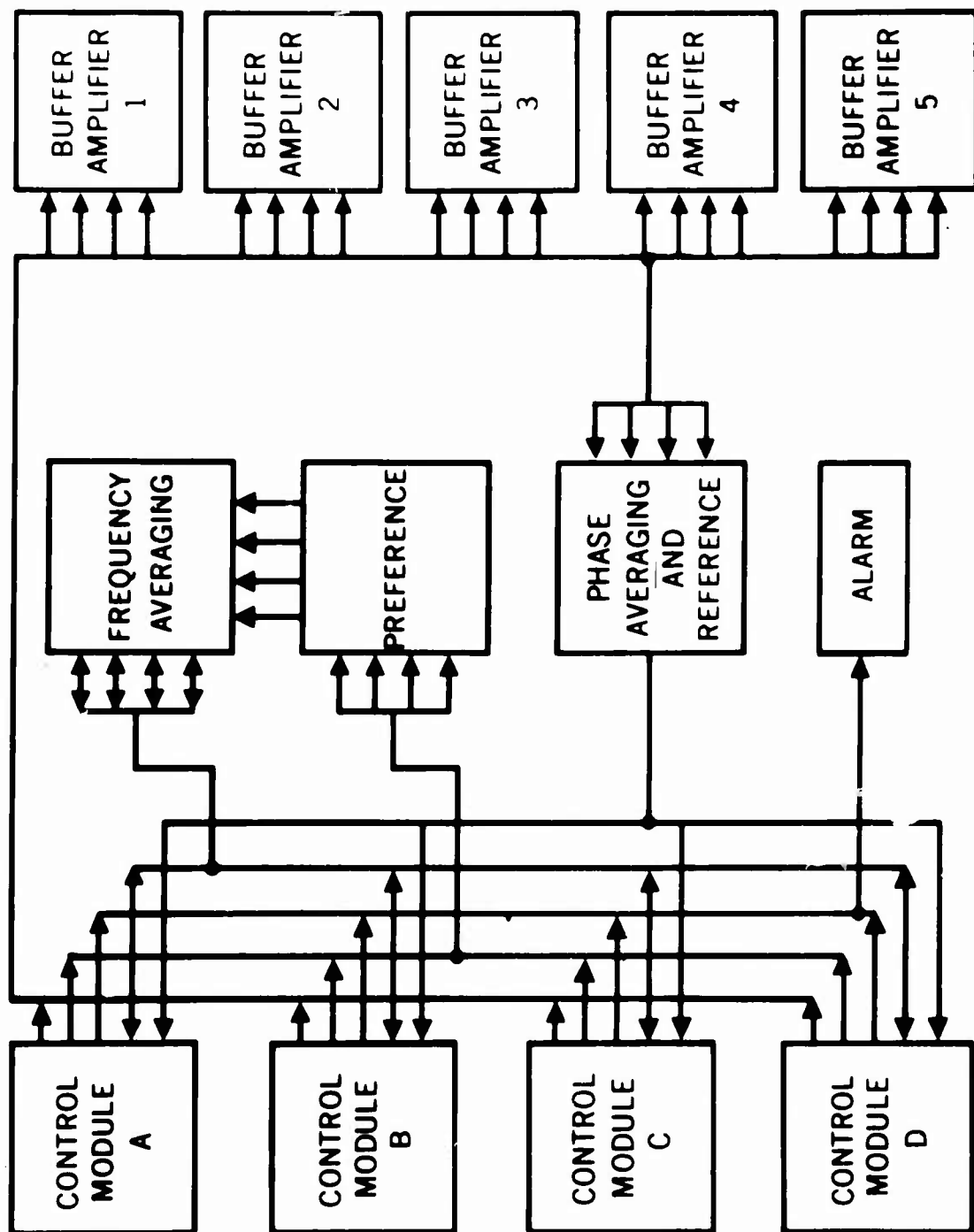
We also have efforts underway to improve clocks, time codes and atomic standards. Two projects of interest are the Frequency Combiner and the Microelectronic Clock. The first slide shows the Frequency Combiner advantages and the second slide is a simplified block diagram. Not shown are the megahertz inputs to each Control Module and identical one megahertz outputs from each Buffer Amplifier.

The microelectronic clock is similar to the unit in use in STADAN except that it is entirely microelectronic. Its characteristics and picture are shown in two slides. A new STADAN timing system using atomic standards, frequency combiner, and microelectronic clock could be contained in one standard seven foot rack.

# **FREQUENCY COMBINER**

1. RELIABILITY BY REDUNDANCY
2. IMPROVED LONG AND SHORT TERM STABILITY
3. IDENTICAL LONG TERM FREQUENCY OUTPUTS FROM SEVERAL CONTROLLED STANDARDS
4. ATOMIC FREQUENCY CONTROL OF QUARTZ STANDARDS
5. DIRECT MONITORING OF AVERAGE FREQUENCY DIFFERENCES AND ACCUMULATED PHASE DIFFERENCES OF SEVERAL STANDARDS
6. ADDED CIRCUITRY AFFECTS SYSTEM RELIABILITY

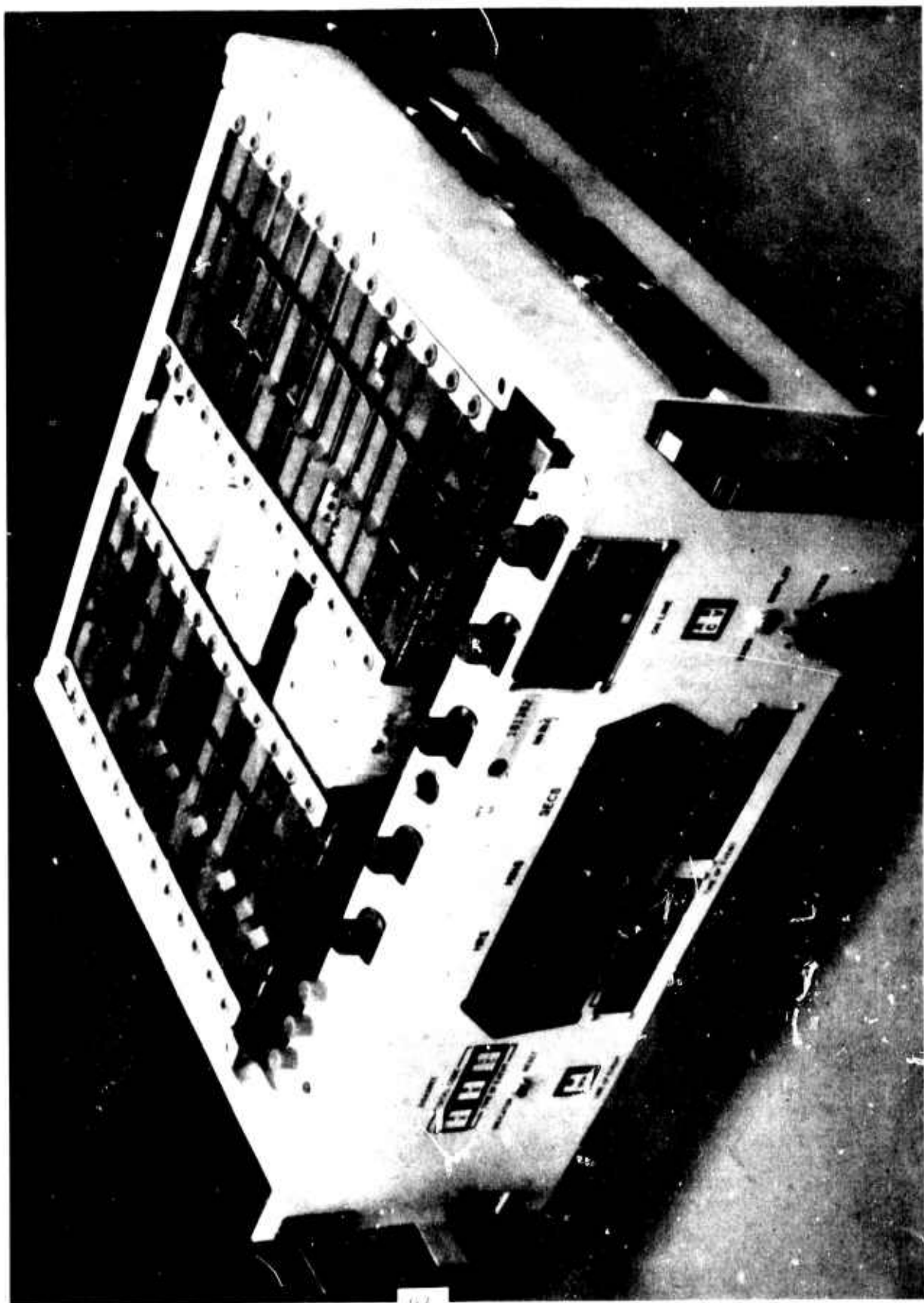
# FREQUENCY COMBINER



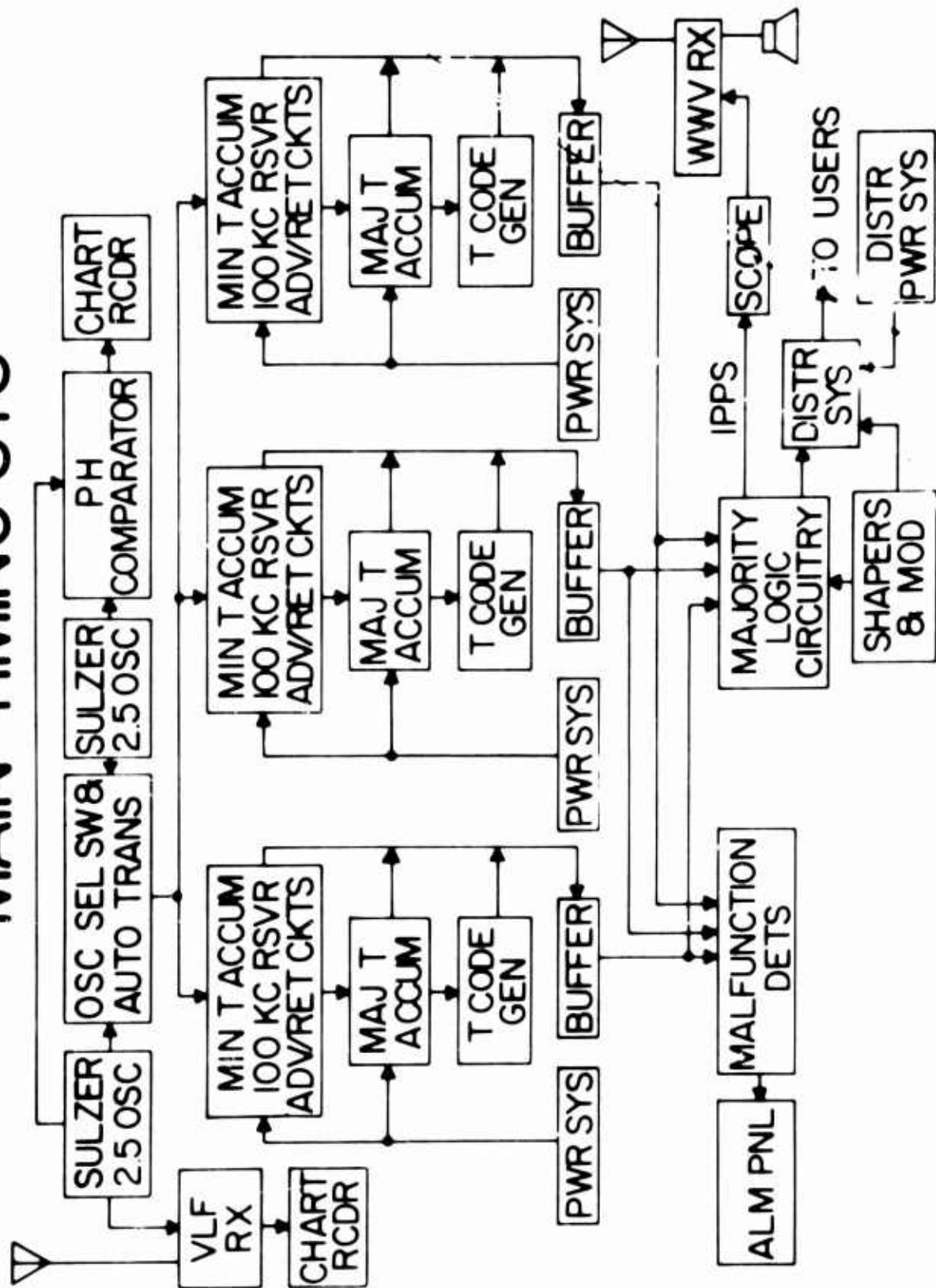
# **MICROELECTRONIC CLOCK**

1. THREE INDEPENDENT CLOCKS INCLUDING POWER SUPPLIES
2. MAJORITY VOTED OUTPUT AND ERROR INDICATORS
3. LOCAL AND REMOTE VISUAL DISPLAYS TO HUNDREDS OF DAYS
4. TIME OF EVENT SELECTION
5. NAS BINARY CODED DECIMAL AND SERIAL DECIMAL TIME  
CODED OUTPUTS
6. H,W,D: 7 X 19 X 18.75; WEIGHT 40 LBS.
7. POWER: 76 WATTS AT 26 VOLTS; TEMPERATURE: 0 TO 50°C
8. REQUIRES 1 MHz FREQUENCY STANDARD INPUT





# MAIN TIMING SYS



REMARKS ON NASA SATELLITE TRACKING  
AND DATA ACQUISITION NETWORK (STADAN)

M. E. Shawe, Code 521

NASA, Goddard Space Flight Center

The STADAN consists of 17 world wide stations. Since the network is primarily a user of time, it is vitally interested in present and future timing systems.

Funds are made available for more accurate and precise timing systems only as justified by a reasonably firm requirement. Thus far the requirements of the experimenters have called for absolute accuracies in the region of one-half second and uniformity or self consistency of milliseconds. At present our firm requirement for greatest accuracy is  $\pm 100$  microseconds based on accuracy of present Range and Range Rate tracking systems. A laser tracking system under development at GSFC may push this to 10 microseconds if that system becomes an operational STADAN tracking system.

Thus at GSFC we are examining synchronization systems including: (1) Portable Clocks; (2) Dual Very Low Frequencies; (3) Loran-C; and (4) Satellites. We intend to select the most desirable in the light of requirements and cost.

Mr. Straton Laios will talk on the present STADAN timing system and methods of synchronization.

Remarks on  
GEOS TIME SYNCHRONIZATION  
by

Straton C. Laios, Head,  
Time Standard Section  
NASA-Goddard Space Flight Center

The Geodetic Earth Orbiting Satellite (GEOS) is presently being utilized to time synchronize the Space Tracking and Data Acquisition Network (STADAN). The GEOS satellite provides a capability of time synchronizing the STADAN to fifty (50) microseconds of Universal Time Coordinated (UTC).

The GEOS spacecraft houses a crystal control clock which produces a time mark (epoch) each minute. The time epoch is transmitted from the satellite and as it passes over a STADAN tracking station it is received and compared to a locally generated one pulse per minute (1 PPM) (Refer to Figure 1).

The timing signal is 186.67 pulses per second square wave which surrounds the spacecraft minute. On the spacecraft minute, a phase reversal occurs in the timing signal. The timing signal phase modulation the 136 MC carrier which is transmitted to the station.

The carrier is received by the station 136 MC telemetry link. The timing signal is demodulated and sent to the Time Recovery Unit. The Time Recovery detects the phase reversal in the timing signal and produces a stop signal which is sent to a time interval counter. The time interval counter measures the interval between the locally generated 1 PPM, which starts the counter and detected phase reversal of the timing signal. This measurement must now be reduced for the slant range between spacecraft and station, delays in the station equipment and the error in the spacecraft. Hence, the time error  $E$  at the station is equal to  $T_m - T_p - T_d - T_{sc}$ .

$T_m$  = the time measured by the counter  
 $T_p$  = slant range in time  
 $T_d$  = station delays  
 $T_{sc}$  = spacecraft error

In order to measure the spacecraft error, the Rosman tracking facility was selected as the master timing station (refer to Figure 2). The time standard at Rosman is synchronized to a precise time standard at GSFC via a microwave link. The three sigma of the round trip delay of the microwave link over the past two years has been ten (10) microseconds.

The same measurement is made at the master station as is made at all stations. However, the error that is reduced from the data is not station clock error but the spacecraft error. This data is now used to correct the data from STADAN and time corrections are forwarded to the stations.

The data collected at Rosman is also used to maintain the spacecraft to within  $\pm$ four hundred (400) microseconds of WWV. This is accomplished by transmitting the proper corrections to the spacecraft.

Since the launch in January 1968, Rosman and \*Fort Myers have been simultaneously measuring the GEOS Timing epoch. The average difference between the two stations measurements over this seven month time span has been forty (40) microseconds. Comparisons between the GEOS Timing Data and Atomic Clocks have been made at Quito, Ecuador; Santiago, Chile; and Winkfield, England. These comparisons were made over a few days and resulted in somewhat better results than the aforementioned.

During the month of May, GEOS Timing Data was compared against Very Low Frequency (VLF) Data at six (6) of the STADAN tracking stations. The oscillators at each of the stations were allowed to run without correction for a two-week period. The accumulated phase error as determined by VLF was compared to the accumulated phase error as determined by GEOS. Following is a table of the results:

STATION	VLF DATA IN MICROSECONDS	GEOS DATA IN MICROSECONDS	DIFFERENCE MICROSECONDS	AVERAGE ERROR/DAY MICROSECOND/DAY
Fairbanks, Alaska	129	117	22	1.6
Johannesburg, South Africa	615	658	43	3.0
Orroral, Australia	272	274	02	0.15
Santiago, Chile	192	172	20	1.4
Tananarive, Madagascar	457	400	57	4.0
Winkfield, England	285	333	48	3.4

The results of all the data collected and analyzed has indicated that Goddard's STADAN is presently time synchronized to within fifty (50) microseconds or better.

\* Fort Myers is time synchronized by LORAN-C ground wave from Jupiter, Fla.

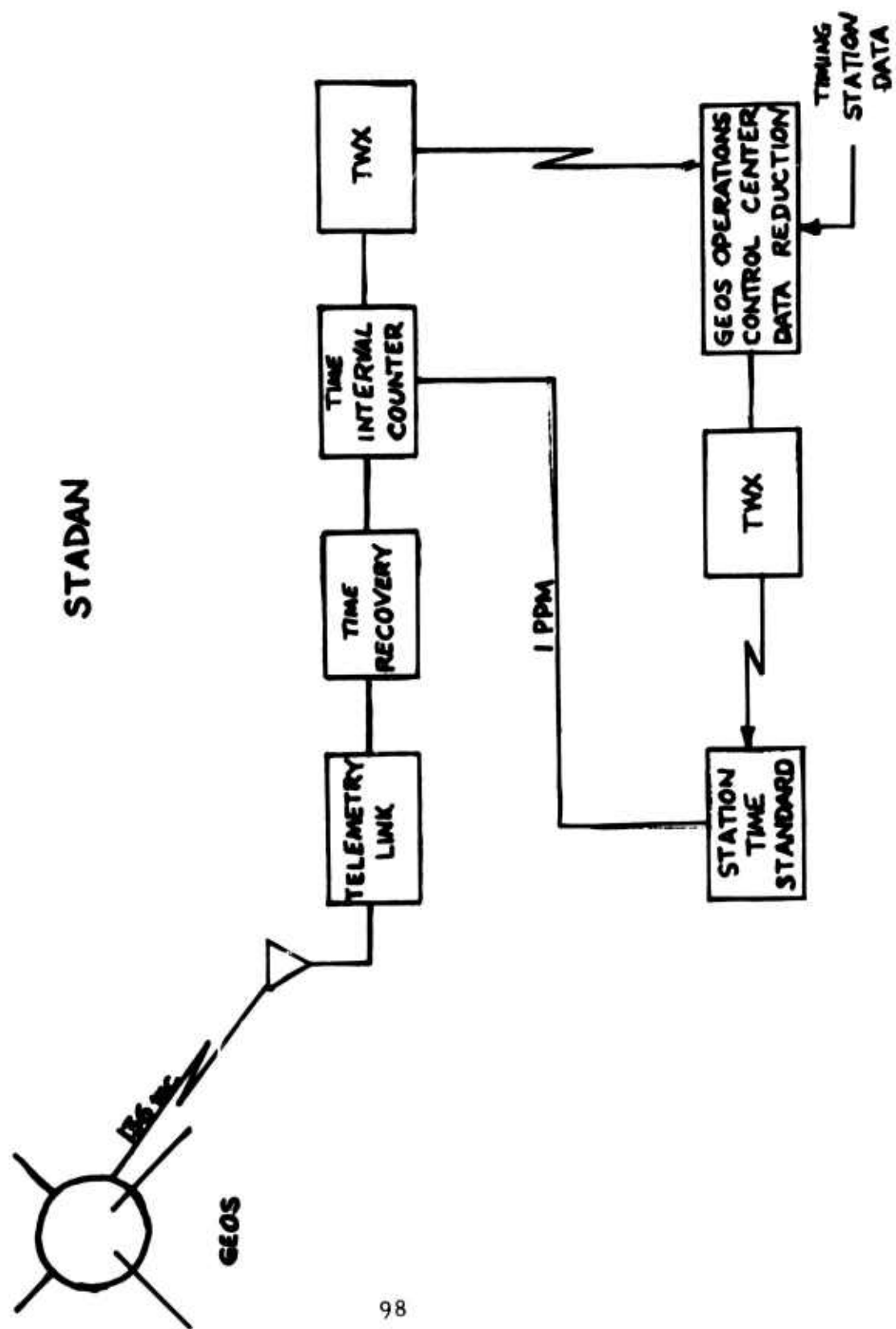


FIGURE 1

# TIMING STATION ROSMAN

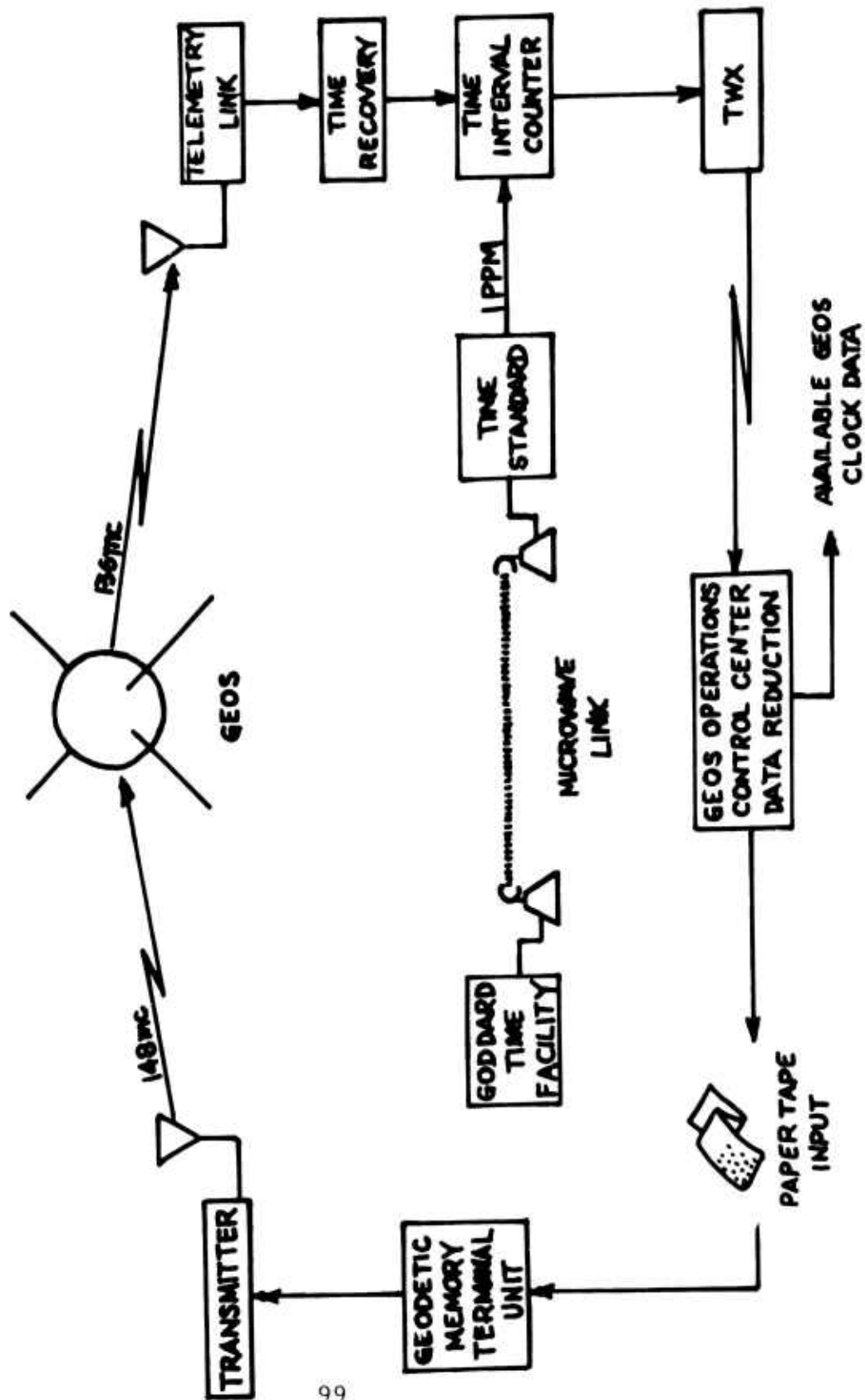


FIGURE 2

Remarks on  
ATS TIME SYNCHRONIZATION

by

Straton C. Laios, Head,  
Time Standard Section  
NASA-Goddard Space Flight Center

The Application Technology Satellite (ATS) will be used in the near future to time synchronize Goddard's ATS stations (Mojave, California and Toowoomba, Australia). These stations are presently using High Frequency transmission for time synchronization and, therefore, time errors of one to two milliseconds can easily occur. These stations can easily be synchronized to within five (5) microseconds by use of the ATS satellite.

The Rosman tracking facility has been selected as the master timing station and Mojave and Toowoomba the slave stations. The reason for the above is that the Rosman time standard is held very close to WWV via a microwave link from the Goddard Time Standard Facility.

Time Synchronization will be accomplished by simultaneously transmitting timing signals between a master and a slave station. Each station starts a time interval counter by the signal it transmits and stops the counter by the signal it receives (Refer to Figure 1). The time error between the station is the time interval measured at the master, designated  $T_m$ , minus the time interval measured at the slave, designated  $T_s$ , divided by two. ( $E = \frac{T_m - T_s}{2}$ ).

$T_m$  is the time interval measured at the master station.  
 $T_{xm}$  is the transmitter delay at the master.  
 $T_1$  is the propagation path from the master to spacecraft.  
 $T_2$  is the path from the spacecraft to the slave station.  
 $T_3$  is the path between the spacecraft and the master station.  
 $T_4$  is the path between the slave and the spacecraft.  
 $T_{xs}$  is the transmitter delay at the slave.  
 $T_{rm}$  is the receiver delay at the master.  
 $T_{rs}$  is the receiver delay at the slave.

The SHF carrier will be modulated by a IPPS timing signal from the station time standard and transmitted via the satellite from the master to the slave and simultaneously from the slave to the master. From Figure 1 it can be seen that:



- 2 -

# ATS TIME SYNCHRONIZATION (cont.)

$$T_m = T_{xm} + T_1 + T_2 + T_{rs} + E$$

$$T_s = T_{xs} + T_3 + T_4 + T_{rm} - E$$

$$T_m - T_s = T_{xm} - T_{xs} + (T_1 + T_2) - (T_3 + T_4) + (T_{rs} - T_{rm}) + 2E$$

Because the spacecraft is synchronous  $T_1 \approx T_3$  and  $T_2 \approx T_4$ . It can be assumed that  $T_{xm} - T_{xs} \approx 0$  and  $T_{rs} - T_{rm} \approx 0$  since the channels used are wide band and should have very little delay in themselves. Also, only the difference delay contributes to error of the technique. This contribution should be in the nanoseconds region. Hence,  $\frac{T_m - T_s}{2} = E$

if the answer is positive the slave station is slow and if the answer is negative the slave station is fast.

Without a rigorous analysis we can easily predict synchronization results of less than five microseconds. However, it appears that more rigorous analysis would provide even better results. The work performed by Dr. Markowitz and others has let one to believe that this and similar techniques will provide time synchronization approaching 0.5 microseconds.

# ATS TIME SYNCHRONIZATION

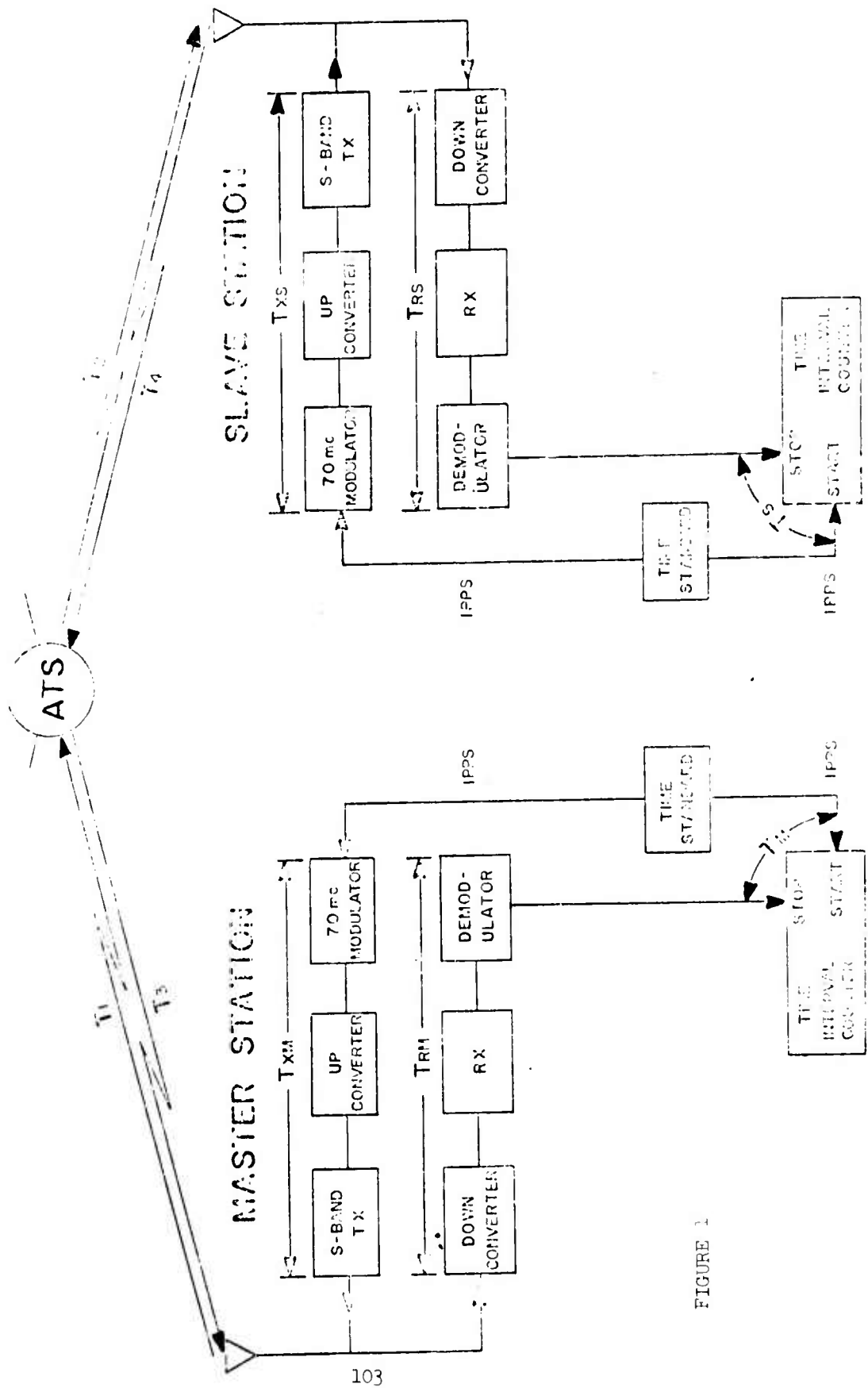


FIGURE 1

Remarks on  
ASTRODATA TIMING SYSTEM

by

Straton C. Laios, Head,  
Time Standard Section  
NASA-Goddard Space Flight Center

The Astrodata Timing System is a highly reliable, redundant, flexible solid state device. It employs triple redundant digital clocks and code generators. Each clock and generator contains its own power system. The power system consists of redundant power supplies and uses batteries as backup power in case of line failure. The digital clocks are driven from one of two Sultzer 2.5 oscillators. In case of failure of one oscillator, the system automatically switches to the other.

The system employs majority logic to drive its distribution system. The majority logic output is the two of the three clock inputs that are the same. Hence, in case of failure of one clock, the user will not see a loss of signal. The timing system also contains malfunction detectors to find errors in the clocks.

The outputs of the system are pulse rates from a 100 K pps to 1 pps in decade steps, sine waves from 5 MC to 60 cps, parallel time of year and the four NASA time codes (NASA 1/sec., 1/min., 1/hr., and the serial decimal time code).

SYNCHRONIZATION EXPERIMENT FOR A TIME DIVISION  
MULTIPLE ACCESS SATELLITE COMMUNICATION SYSTEM

W.K. Allen  
NASA/Goddard Space Flight Center  
Greenbelt, Maryland

J.G. Dunn  
ITT Federal Laboratories  
Nutley, New Jersey

Time division multiple access (TDMA) and other systems by which several ground stations can share a wideband satellite transponder have been compared in the literature.<sup>1</sup> TDMA is potentially capable of high efficiency because none of the transponder output power need be wasted in intermodulation noise. In addition, TDMA does not require transmitter power control as other techniques do. However, a TDMA system requires network synchronization to realize these advantages.

In TDMA, each ground station transmits information bursts which are timed to arrive at the satellite in time intervals relative to bursts from other stations. The phasing of the transmitted signals must then be adjusted to compensate for the difference in range of the satellite to the various stations. For medium altitude satellites, the range is continuously changing and the continuous phasing adjustment results in a frequency offset; the doppler which is proportional to the rate of change of range.

A synchronization experiment for a TDMA satellite system is being conducted by ITT Federal Laboratories under direction of the NASA Goddard Space Flight Center. This system is an outgrowth of a doppler compensation technique developed and tested by NASA in 1965. The compensation technique maintains a sync signal at the satellite whose frequency is essentially unaffected by doppler.

The TDMA format, figure 1, chosen for this experiment is based on the real time transmission of information and provides for 1 sync burst and 10 data bursts of 10  $\mu$ s duration, each with a guard time of 1.25  $\mu$ s between bursts. Synchronization is by doppler tracking where one master station tracks the doppler actively and the slave stations track it passively. The sync burst is modulated by a nominal 800 khz tone which is harmonically related to the frame rate and is used for all time divisions in the format.

The master station transmits the sync burst consisting of 800 khz minus its own doppler of the 800 khz and receives it as 800 khz plus its own doppler. The transmitted frequency is adjusted so that the sum of the transmitted and received frequencies is a constant. This method of doppler tracking assures that the sync tone at the satellite is a true 800 khz.

A slave station receives the pulsed tone from the master station via the satellite. Since the tone was a true 800 khz at the satellite, it will be received with the true doppler of the slave station. The slave station uses this to preset its transmitted frame rate by a technique identical to that used by the master station for doppler tracking. The slave station uses a PN code ranging technique to determine the correct initial phase for its transmitted format.

Two TDMA terminals were constructed for feasibility experiments, figure 2. Each terminal is designed to function either as a master or a slave station. These terminals were installed in the Nutley ground station to share the station transmitter and receiver front end, but otherwise to function independently.

The Relay II, medium altitude satellite, has been used in system tests. The one-way propagation delay for Relay II varies from 7 to 38 ms and the maximum doppler is 17 parts/10<sup>6</sup>. A large variety of experiments have been conducted with the satellite in which many of the terminal parameters have been varied. The timing accuracy between master and slave is consistently better than the 1.25  $\mu$ s guard time under all orbit conditions. The acquisition procedure includes automatic search modes but uses manual switching between modes and manual doppler preset for the loops. The total acquisition time for a terminal is typically between 5 and 20 seconds.

1

Schwartz, et. al. "Modulation techniques for multiple access to a hard-limiting satellite repeater", Proc. IEEE, Volume 54, pp. 763-777, May, 1966.

Note:

Abstract, paper given at International Conference on Communications 1967 Comm. Tech. Group - Space Comm. Committee, Minneapolis, Minn. June 12-14, 1967.

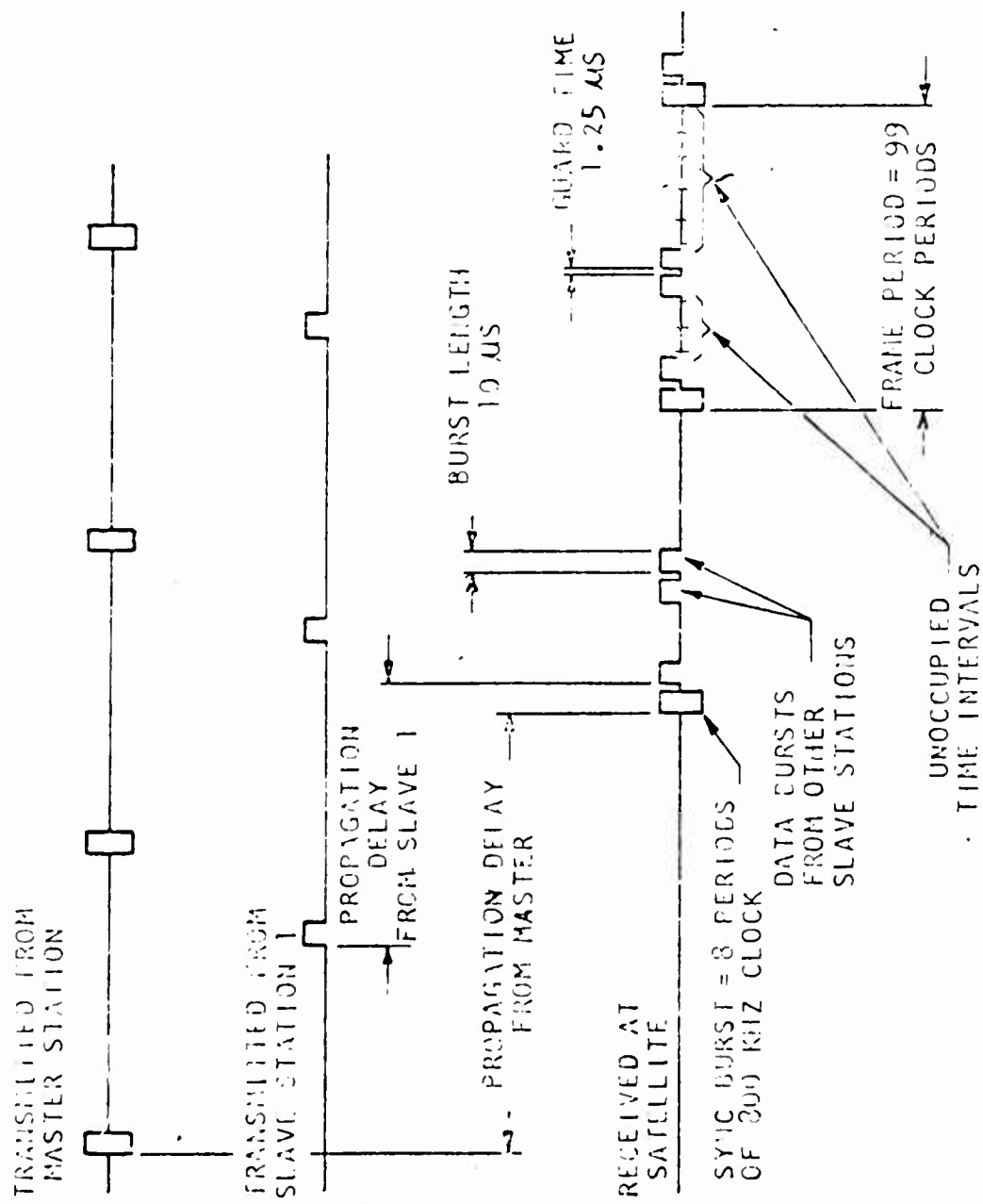


FIGURE 1  
TDMA SYSTEM TIMING

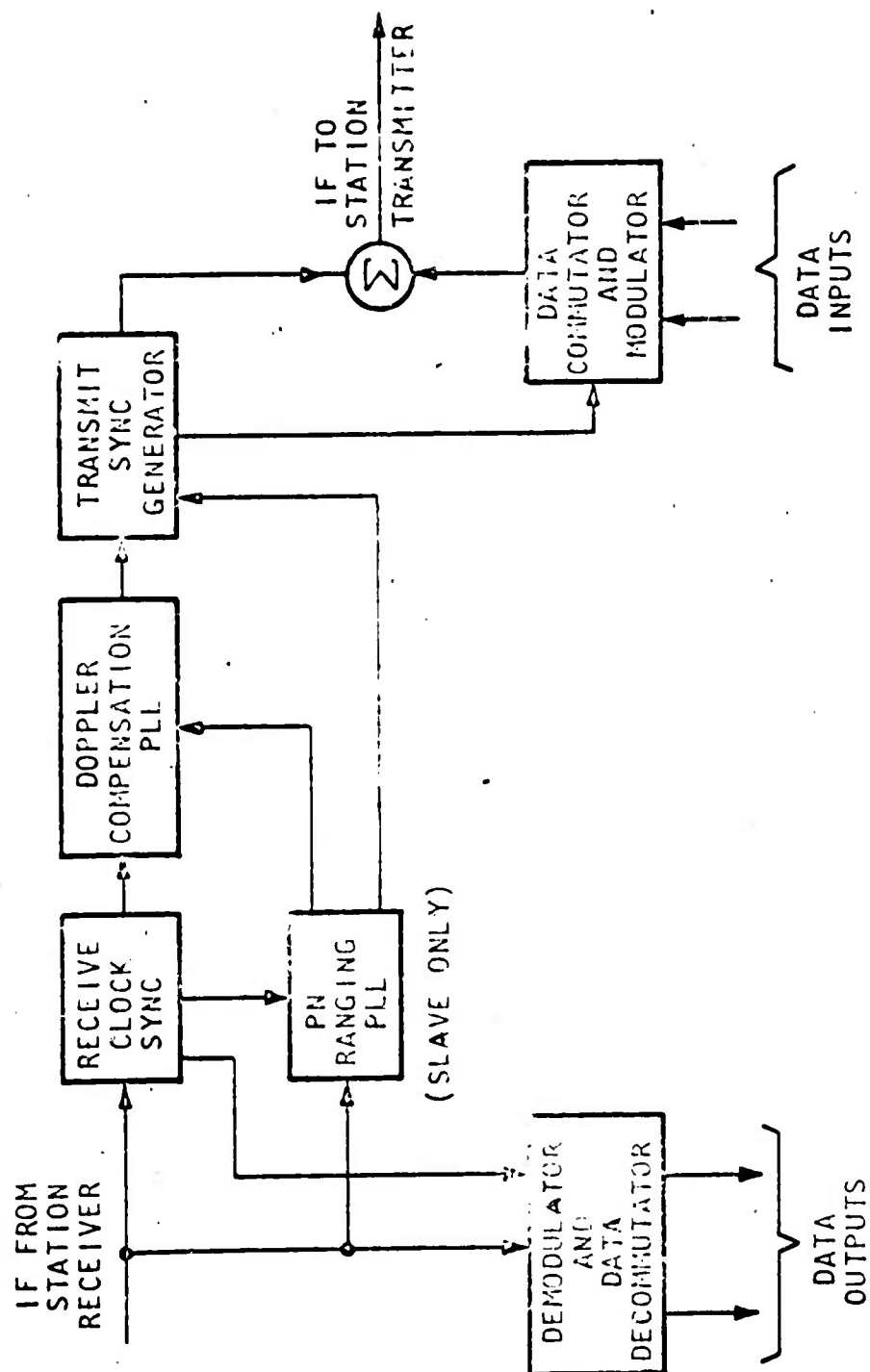


FIGURE 2  
TDMA TERMINAL  
BLOCK DIAGRAM

## World-Wide Time Review

By

G.M.R. Winkler

It is necessary to review basic principles and concepts to establish values and to scrutinize goals in order to evaluate the many possibilities which exist or have been proposed for long distance synchronization. One single time reference or several independent systems: Today one single reference is the only feasible approach from a purely economical point of view.

However, cost versus redundancy and the status of a proposed method in the research and development cycle are additional important points. Up to now, precision timing has been provided (with the notable exception of WWV) as a piggyback operation superimposed as a secondary mission to navigation and communication services. I believe that this principle of economy is still far from being exhausted.

International Aspects of Clock Time Scales: Improved international cooperation, centrally coordinated by the Bureau International de l'Heure (B. I. H. ), is being attempted at the present time. A considerable improvement in the operations of the coordinated clock time scale, UTC, will be necessary for the realization of precision sub-microsecond world-wide timing. Steps for such an improvement on an international basis have been taken (CCIR Interim Meeting Document No. 70). Our proposal calls for the abolishment of frequency offsets and for steps of 1 second in the future UTC system. The navigators do not like this yet.



Performance of Atomic Clocks: For all practicable purposes, the cesium beam clock is the only clock readily available with a performance allowing a sub-microsecond synchronization under operational conditions. Data on the performance of portable clocks, together with experience of the operation of cesium beam clocks in the laboratory, indicate that it is entirely sufficient to synchronize once per week in order to maintain such microsecond internal system synchronization. The two data which proved that this is possible are (a) the RMS closure errors of the U.S. Naval Observatory's four portable clocks in more than 30 trips of 20 to 30 days' duration (one microsecond); and (b) the range of RMS deviations from a linear performance of the U.S. Naval Observatory's cesium beam clocks from between 55 nanoseconds to one microsecond RMS for a 100-day interval with a daily sampling. In order to provide sufficient reliability, a minimum redundancy of 3 to 4 clocks in a timing center is necessary. At the same time, this redundancy will invariably improve the available precision by revealing sudden frequency changes of any one standard.

The question of averaging of phase and frequency in an automatic combiner versus computer evaluation of independently running clocks must be decided individually according to requirements. Most applications in conjunction with an existing computer will be better off by having the computer average and monitor the individually operating clocks. On the other hand, in the absence of such a computer, operational convenience may dictate the use of an additional phase combiner.

Synchronization Techniques: In reference to the principles mentioned above, particularly the availability in the R&D cycle, it is my opinion that the following order of synchronization techniques can be recommended for the purpose at hand:

- a. Portable clocks or flyover services once per week
- b. Loran-C as backup
- c. Satellite synchronization for the future (5 years or later)
- d. Omega/WWVL/Loran-C skywave

For local synchronization links, the application of the television pulse technique reported in the September issue of the IEEE Group for Instrumentation and Measurement Transactions, 1967, is the most economical and operationally convenient method, particularly where microwave links are not available.

A general principle in regard to all one-way timing systems exists in the following. The secondary use of an electronic navigational system offers the operational convenience that the one-way propagation time follows directly from the navigation geometry. This convenience is available with all electronic navigational systems as Loran-C, Omega, and all satellite navigational systems. The existence of the navigational requirement not only provides all the operational and financial support required, but in addition allows the measurement of one-way propagation time directly from the system.

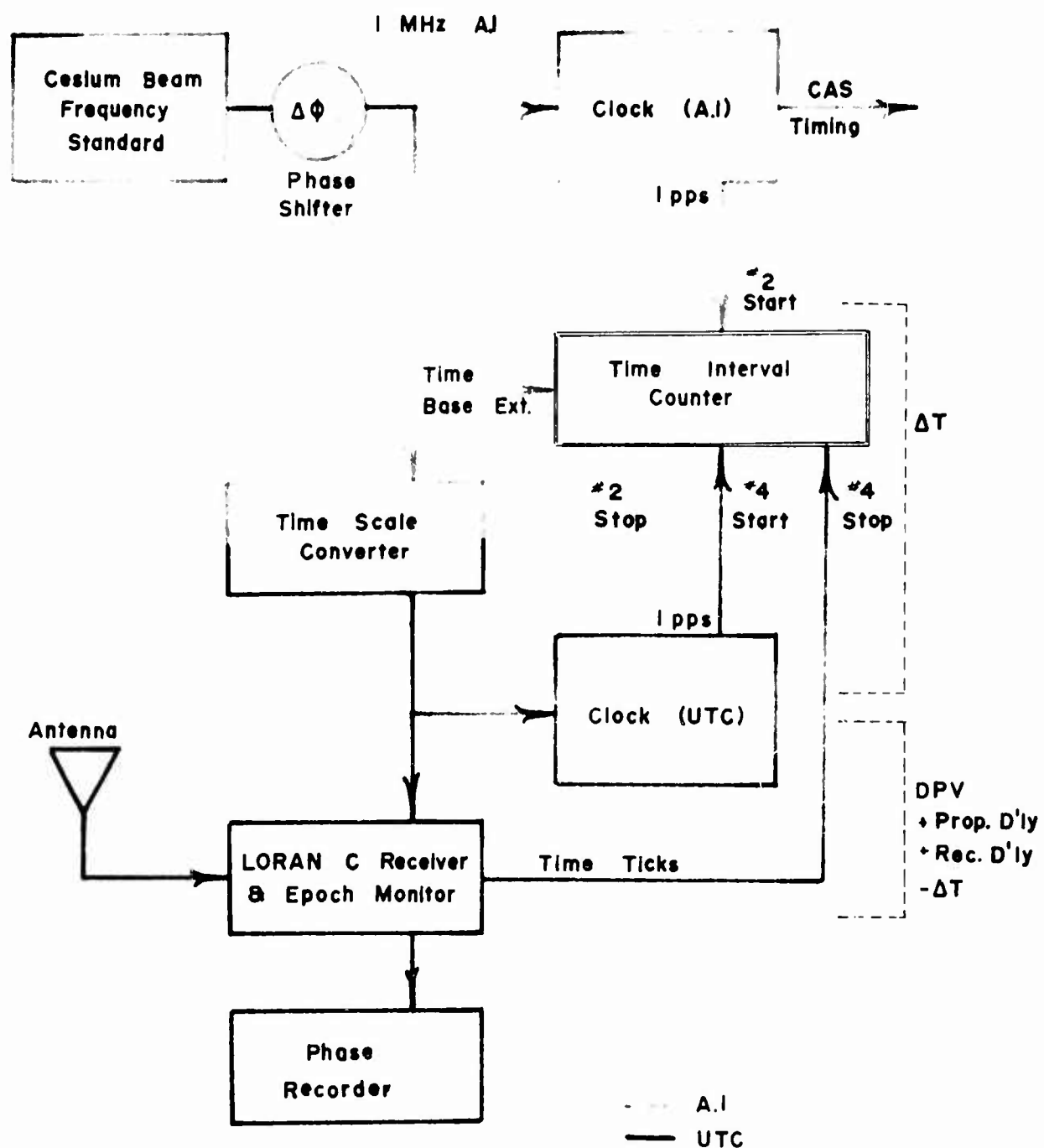
In regard to the Loran-C system, the following amplifying comments apply. The system is in the operational status. The remaining chains can be

synchronized at very little additional cost. The cost for receiving equipment is probably the lowest for all precision timing systems. The integration of the timing function with a navigational function allows additional uses to be derived for navigational purposes. (Rho, Rho)

Satellite Systems: There is no doubt that precision in the order of tens (10s) of nanoseconds is available with two-way satellite microwave links. Relay II established a precision of .1 microsecond (Markowitz). The disadvantage is the high cost of the two-way link and the relatively high cost for the ground stations. On the other hand, it seems clear that one-way satellite timing will not provide the precision asked for in the present systems (.5 microsecond, 3), at least not in an operationally convenient way unless the timing function is again superimposed on an improved navigation system. Such a system is not yet clearly and definitely visible above the R&D horizon. A replacement cost of a system of synchronous timing satellites is extremely high, taking an average lifetime of two to three years into account.

In summary, it appears that not enough experience in an operational sense exists in regard to satellite timing of sub-microsecond precision to justify the freezing of a design at the present state.

# TYPICAL GROUND STATION TIMING SCHEME



RK/66

## RECOVERY FROM COMPLETE STOPPAGE

1. Set UTC clock to WWV - Prop. delay ( $\pm 1$  ms).
2. Set clock (A) to approximate A.1 according to the first step of the checking routine. (Measurement #2)
3. Set UTC Epoch Monitor and lock Loran-C Receiver.
4. Measure UTC clock - Loran-C = DPV + Rec. Delay + Prop. Delay -  $\Delta T(A)$   
(Measurement #4)
5. Shift 1 MHz Phase to remove  $\Delta T(A)$ .

# CHECKING ROUTINE

DATA; MEASURED CLOCK (A) - LORAN-C (REC)  
 FIXED LORAN-C (EM) - LORAN-C (REC) = PROP. DELAY + REC. DELAY

FROM USNO UTC (USNO) - LORAN-C (EM) = DPV (Series #4)  
 A.1 - UTC (USNO) = (Series #7)

"TABLE"

CALCULATION OF A.1 - CLOCK (A) =  $\Delta T(A)$

A.1 - UTC (USNO)	Series #7 + "Table"
UTC - LORAN-C (EM)	Series #4
LORAN-C (EM) - LORAN-C (REC)	FIXED
- [CLOCK (A) - LORAN-C (REC)]	MEASURED

SUM = A.1 - CLOCK (A) =  $\Delta T(A)$

EXAMPLE for measurement made 5 August 1968 at 6<sup>h</sup>04<sup>m</sup>07<sup>s</sup>UT

A.1 - UTC (USNO) Series #7	6.702 333.7
Table for hours	648.0
for minutes	7.20
for seconds	.21
<hr/>	
A.1 - UTC (USNO)	6.702 989.11
UTC - LORAN-C (EM) Series #4	-5.8
	6.702 983.3
Propagation Delay (example)	2 223.7
	6.705 207.0
Receiver Delay (example)	25.4
	6.705 232.4
- [CLOCK (A) - LORAN-C (REC)] (example)	- 6.705 231.7
<hr/>	
A.1 - CLOCK (A) = $\Delta T(A)$	0.7 $\mu$ s

That is, CLOCK (A) is 0.7  $\mu$ s behind A.1

A.1 - UTC for every second of a day  
to be added to value pub-  
lished in #7 for 0 hrs UT

(Unit in 1 microsecond)

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U. S. NAVAL OBSERVATORY  
WASHINGTON, D.C. 20390

19 June 1968

DAILY RELATIVE PHASE VALUES, SERIES 4

NO. 72

Reference: (a) Supplement No. 4 to Daily Phase Values of 19 October 1967

The table gives: (USNO - Station)  
Unit = one microsecond

Freq. (kc/s-UTC)	1		2*		3*		11		4		10		9	
	LORAN-C	Cape Fear	LORAN-C	Johnston I.	LORAN-C	Iwo Jima	$\Omega$ /NY	$\Omega$ /T	$\Omega$ /T	$\Omega$ /NY	$\Omega$ /NY	$\Omega$ /H/D		
	100	100	100	100	100	100	10.2	12.0	12.0	12.5	12.5	13.6		
1968 June	13	- 6.9	-	-	14.5	14.5	1,000.0+	11,000.0+	11,000.0+	1,000.0+	1,000.0+	25,000.0+		
	14	- 7.1	-	-	14.4	14.4	767	578	578	797	797	908		
	15	- 7.0	-	-	14.5	14.5	769	573	573	797	797	911		
	16	- 7.0	-	-	14.6	14.6	769	578	578	797	797	912		
	17	- 7.0	-	-	14.6	14.6	769	578	578	797	797	911		
	18	- 7.0	-	-	14.6	14.6	770	573	573	798	798	911		
	19	- 7.0	-	-	14.7	14.7	770	578	578	798	798	912		
												914		

Freq. (kc/s-UTC)	13		12		8		5		6		7		14	
	GBR	NAA	NLX	WJVL	NSS	NBA	CYZ40							
	16.0	17.8	18.6	20.0	21.4	24.0	80.0							
	19,000.0+	3,000.0+	12,000.0+	8,000.0+	11,000.0+	11,000.0+	2,000.0+							
1968 June	13	53	448	109	166	124	839							
	14	50	449	109	165	125	836							
	15	49	448	109	165	125	835							
	16	47	448	109	166	127	882							
	17	45	448	107	166	127	879							
	18	45	448	108	166	128	877							
	19	44	448	107	165	123	878							

\*Measured by USNO Time Reference Station within ground wave range but corrected to refer to USNO Master Clock.



NOTE:

(1) NAA	2000 UT	12 June	step	plus 1
	1800 UT	13 "	"	plus 1
	2250 UT	14 "	"	minus 1
	1050 UT	16 "	"	plus 1
	1355 UT	17 "	"	plus 1
	1755 UT	17 "	"	minus 1
	1050 UT	18 "	"	plus 1
	2255 UT	18 "	"	minus 1
	1055 UT	19 "	"	plus 1
CYZ40	1455 UT	19 "	"	plus 2

All Omega frequencies except 12.5 and 12.6 retarded 1.6 microseconds 1235 UT 14 June.

(2) Propagation disturbances observed on some transmissions

13 June about 1200 and 2015 UT
14 " " 1545 UT
15 " " 2155 UT
16 " " 1650 UT
18 " " 1920 and 2040 UT
19 " " 1415 and 1745 UT

(3) All LIJ readings taken at 0500 UT.

(4) USNO Time Reference Station Clock Cs 143 in Richmond, Florida, was measured to be 5.9 microseconds behind USNO Master Clock in Washington, D. C. on 29 May 1968 at 1916 UT.

U. S. NAVAL OBSERVATORY  
WASHINGTON, D.C. 20390

7 August 1968

NO. 79

DAILY RELATIVE PHASE VALUES, SERIES 4

Reference: (a) Supplement No. 4 to Daily Phase Values of 19 October 1967

The table gives: (USNO - Station)  
Unit = one microsecond

Freq. (kc/s-UTC)	LORAN-C		Loran-C*		9	1	8	7
	Cape Fear	Johnston I.	Iwo Jima		Q/NY	Q/T	Q/NY	Q/H/D
	100	100	100					
1968 Aug. 1	- 6.3	13.8	14.2		10.2	12.0	12.5	13.6
2	- 6.3	13.5	14.2		1,000.0+	11,000.0+	1,000.0+	25,000.0+
3	- 6.5	13.9	14.2		768	577	796	911
4	- 6.1	13.7	14.3		769	577	796	913
5	- 5.8	13.7	14.2		768	577	796	912
6	- 5.9	13.7	14.2		769	577	795	911
7	- 5.9	13.7	14.2		769	577	795	912

Freq. (kc/s-UTC)	LORAN-C		Loran-C*		2	3	5	11
	Cape Fear	Johnston I.	Iwo Jima		W/VL	NSS	NBA	CY240
	100	100	100					
1968 Aug. 1	- 75	445	445		20.0	21.4	24.0	80.0
2	- 76	444	444		8,000.0+	11,000.0+	11,000.0+	2,000.0+
3	- 75	445	445		110	---	185	---
4	- 76	445	445		110	---	188	---
5	- 77	444	444		110	---	190	---
6	- 76	445	445		110	---	191	---
7	- 76	444	444		110	---	190	---
924 (Note 2)	924	444	444		110	176	192	---

\* Measured by USNO Time Reference Station within ground wave range but corrected to refer to USNO Master Clock.

NOTES: (1) Correction:  $\Omega$ /H/D July 28 913  
 29 913  
 30 910  
 31 913

(2) GBR constant to be added, changed from 19,000 to 18,000.

(3) NAA 1955 UT 31 Jul step minus 1  
 1455 UT " 2 Aug " minus 1  
 1625 UT " " " plus 1  
 1355 UT " " " minus 1  
 1655 UT " " " plus 1  
 1055 UT " " " plus 1  
 1655 UT " " " minus 1  
 1055 UT " " " minus 1

All Omega frequencies except 12.5 and 12.6 retarded 1.0 microsecond 1235 UT 2 August.

(4) Propagation disturbances observed on some transmissions  
 5 Aug about 1420 UT  
 6 " " 1320 UT

(5) NSS phase value not coherent with phase values published before station went off air for maintenance.

U. S. NAVAL OBSERVATORY  
WASHINGTON, D.C. 20390

25 July 1968

PRELIMINARY TIMES AND COORDINATES OF THE POLE, SERIES 7

NO. 30

I. EXTRAPOLATED CORRECTIONS

Extrapolated corrections of coordinated time signals are issued by the U. S. Naval Observatory weekly with the predictions two weeks in advance.

These predictions are based on observations of UT2 made at Washington and Richmond. Linear curves are fitted to the unweighted, nightly results of 1, 2, and 3 months observations at each station separately. The curves are extrapolated and combined into a single value giving Richmond a weight of two and Washington a weight of one. Experience and judgment are used if the results from the 1, 2, or 3 months curve fitting differ extensively, the last observed month being given the largest weight.

Thus the predictions are the difference UT2-UTC(USNO). However, they are equally accurate for all coordinated time signals. The estimated accuracy is about .005 seconds.

Date 0 <sup>h</sup> UT	MJD	A.1-UTC(USNO)	Extrapolated UT2-UTC(USNO) Rate = 1/4 ms/day
1968 Aug. 1	40069	6.691 965 7	+ 0.026
2	40070	6.694 557 7	+ 0.026
3	40071	6.697 149 7	+ 0.026
4	40072	6.699 741 7	+ 0.027
5	40073	6.702 333 7	+ 0.027
6	40074	6.704 925 7	+ 0.027
7	40075	6.707 517 7	+ 0.027

JD = MJD +2,400,000.5

ET = A.1 +32.15

## II. PRELIMINARY EMISSION TIMES for Signals from NSS, NBA, GBR, WWV, CHU, and Other Coordinated Stations

The following times for coordinated stations are derived by averaging observations of UT2-UTC made at Richmond, Florida; Washington, D. C.; and Herstmonceux, England. B.I.H. corrections for each station are used to reduce the individual values of UT0-UTC to UT2-UTC before averaging.

The following table gives values of UT0-UTC, UT1-UTC, and UT2-UTC as the differences in the readings of clocks. B.I.H. corrections are used to reduce UT2-UTC to UT1-UTC. The value of UT0-UTC is obtained from UT1-UTC by correcting for the variation in longitude of Washington as given by the B.I.H. (Conventional Pole).

UT0 is the reading of a clock which indicates time UT0. Similarly for UT1, UT2, and A.1. "UTC" is the reading of the transmitting clock.

For 24 July 1968 at 1500 UT

UT0 - UTC,	+ 0 <sup>s</sup> .010
UT1 - UTC,	+ 0.013
UT2 - UTC,	+ 0.017
A.1 - UTC,	6.673

## III. PROVISIONAL COORDINATES OF THE POLE

For 24 July 1968

B.I.H.	x	y
Conventional International Pole	+ 0 <sup>s</sup> .101	+ 0 <sup>s</sup> .177

REMARKS ON THE APPLICATION OF RF SPECTROSCOPY OF  
STORED IONS TO FREQUENCY STANDARDS

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The desirability of an ultrastable clock which can be carried aboard an aircraft is clearly evident both in the context of Dr. Winkler's remarks on the flying clock method of time synchronization of remote stations, and for providing a simpler alternative to frequent resynchronizations of user aircraft clocks.

The long term stability of atomic frequency standards is determined by uncontrollable random perturbations from the environment on the atoms whose microwave transition frequency is used as a reference. Achievement of long term stability requires the localization of the atom for the purposes of observing their interaction with the microwave field while retaining a high degree of isolation from the environment. It is in the manner in which this isolation is approximated that distinguishes the various types of standards. Thus, in the Cs beam the atoms are observed in free flight; in the Rb standards the atoms collide with inert gas particles and in the Hydrogen maser the atoms collide with a polymerizing plastic-teflon which fortunately is extremely effective in that about  $10^4$  collisions are required on the average before the radiating atom is lost. However, even in the H-maser there is inevitably a residual perturbation due to the wall collisions which will ultimately lead to fluctuations over a sufficiently long time.

The way to reach beyond the present long term capabilities of atomic standards in a reasonably portable device may perhaps lie in a radically new direction. The results of recent university research on the rf spectroscopy of charged particles, atomic ions, promise to have a striking application in the field of frequency standards. Ions may be trapped in specially tailored high frequency electromagnetic fields in high vacuum without interacting with matter for periods exceeding by orders of magnitude what has hitherto been possible with neutral atoms. This means that exceedingly small fractional line-widths are achievable. Thus, for example, a promising system utilizing the ion of the mass 199 isotope of mercury, which has a hyperfine frequency of about 40 GHz would have a fractional line-width of about  $10^{-12}$  for a containment time of about 10 seconds, a routinely attainable value.

There are of course limitations and difficulties - principally the small number of ions which may be contained and hence the expected poor signal to noise ratio. However, the figure of merit of a standard  $F$  is given by  $F = S/N (f_0/\Delta f)$  and even though  $S/N$  is small,  $F$  can still be large because of the small fractional line width. In any event this figure of merit reflects the short-term capabilities of the standard for which no claim of improvement is made and which is not as important as long term stability for time-keeping. The other problem is that of state inversion in the ion system. For this, optical pumping or spin-dependent atomic collision processes are available. If optical pumping is used, as Dr. E. Hafner pointed out, there will be the "light shift" in the frequency to contend with. There are several schemes possible to circumvent this problem: (1) pulsing of the light; (2) optically pumping the nuclear state of the neutral atom before ionization; and (3) use such low intensity of light as is compatible with the (long) relaxation time of the ion; this ensures that the light shift, which is expected to be no more than a few percent of the broadening due to the light, in the above example would not exceed a few parts in  $10^{14}$ . Since the ions are trapped in a region on the order of the microwave wavelength (7.5mm) the system should be no larger in size than the portable Rb standards - perhaps even smaller.

Details of the techniques for the radio frequency spectroscopy of stored ions are contained in the following publications:

H. G. Dehmelt and F. G. Major, Phys. Rev. Letters 8, 213 (1962).

E. N. Fortson, F. G. Major and H. G. Dehmelt, Phys. Rev. Letters 16, 221, (1966)

F. G. Major, and H. G. Dehmelt, Phys. Rev. 170, 90 (1968)

## APPENDIX I

### FAA PWI-CAS Projects

#### Summary of Prior Work

##### Pilot Warning

Minneapolis-Honeywell. This device was based on the principle of infrared emission from intruding aircraft and provided warning to the pilot of direction so that he could then attempt to visually acquire the intruder. Distance to the intruder was not provided.

Navy Ordnance Test Station, China Lake, California. In the mid-1950 period preliminary tests were conducted using aircraft engines as infrared sources. Results of these tests were not promising. Tests thereafter utilizing infrared emission from high intensity anti-collision beacons on aircraft stabilizers provided detection up to ten miles.

Cornell Aeronautical Laboratory. Direct projection of high brightness images was found to be partly successful.

Motorola, Inc. Motorola experimented with a metric wave PWI. It was found that interference, false targets, and poor angular resolutions resulted in unsatisfactory performance.

Other PWI Effort. A host of programs was initiated, some under Government sponsorship for increasing skin reflection for visual observation of the treated aircraft by other aircraft. These were found to be generally unsatisfactory for adequate proximity warning.



Sperry Gyroscope. This FAA-sponsored program had as its purpose full CA for commercial airlines, partial CA and PWI for well instrumented private aircraft, and PWI only for small private planes. The equipment consisted of a transponder, a flush-mounted Luneberg lens antenna, and an analog system of encoder, decoder, computer and simulated noise equipment. The interrogator radar beacon scanned each two minutes. The transponder receiver employed a directional antenna with a 30 rpm scan rate. Received signals included relative bearing, velocity, altitude, and air speed. Accuracy was claimed to be 50 feet. Elapsed time between scanning and evaluation of response for maneuver indication was two to four seconds. The system performance advantages were outweighed by the disadvantage of system weight and size. Cost of the installed airborne equipment was prohibitive to operators.

Bendix Corporation. The Bendix ground-bounce system employed the ratio of aircraft separation distance to closure rate. This ratio is symbolized by the Greek letter Tau from which is derived the nomenclature "Tau System." The system operates as follows. All aircraft transmit pulses spaced so as to provide altitude information. A listening aircraft receives a direct pulse and an echo pulse which bounces from the ground. If the aircraft are at a common altitude, the collision threat is evaluated. With aircraft knowing its own altitude, that of the intruder

and the time difference between the direct and the first ground-bounce, the separation distance can be computed. Successive pulses provide the rate at which the range is changing. The time remaining before the plane must execute its escape maneuver is calculated. At a pre-selected time the threatened aircraft changes altitude upward if above the intruder, or downward if below. A major disadvantage of the system was ground-bounce error based upon terrain contour.

National Company. The National technique employed the same collision threat criteria as that proposed by Bendix Corporation. Like the Bendix system, it is cooperative in nature and transmits a message indicating own barometric altitude. In place of the Bendix ground-bounce ranging technique to measure aircraft separation, National employed a precisely controlled, specifically assigned time slot. An aircraft in receiving a message from other aircraft within range notes the time of message arrival with respect to its own frequency/time standard and compares this with the last assigned transmit slot to determine the time required for message transmit. This is directly equated to distance between the aircraft with each microsecond of transmit time equal to approximately 1,000 feet of separation.

Where Bendix determined closure rate by measuring change-of-separation between times of several transmissions, the time slot technique employed by National instantaneously determined closure rate by measuring

doppler shift of the received signal referenced to its own frequency/ time standard. Thus, range and range rate were determined in a single one-way transmission. Each one-way transmission made once per second (for example) was independent of other transmissions and eliminated averaging.

A solution to the requirement for high stability was found in the use of low-cost crystal oscillators frequently updated from ground stations employing an atomic oscillator and using an assigned time slot for updating transmission.

A major area for further study is the use of the technique in the high density terminal area. The accuracy of the range measurement by a single one-way transmission appears to offer a range/altitude mode that would not be sensitive to established, or planned, air traffic control practices.

The technique appears to permit considerable reduction in cost for airborne equipment placing major share of expense on ground facilities. In turn, the ground facilities are thus enabled by virtue of the data available to ground stations to perform the full functions of ATC.

McDonnell Aircraft. A company-sponsored program by McDonnell Aircraft employed the time and frequency technique to provide aircraft separation in the company operated flight test range. This is a single station operation wherein initial ground synchronization of stable clocks

and ground/air updating is utilized. The design is cooperative, employs time sharing, and is physically mounted in external pods on the aircraft.

Collins Radio. In recognition by the FAA that test of collision avoidance equipment of cooperative nature in high density terminal environments obviously included the risk of false alarms which might cause collisions where no hazard initially existed, Collins was placed under contract to simulate actual environmental conditions. Collins has evaluated the merit of three different techniques: ground-bounce, interrogator/transponder, and time frequency.

In early tests of range altitude systems, computer analysis found that moderate turning rates of less than three degrees per second did not produce many false alarms in the terminal area, but warning time for evasive maneuvers could be sharply reduced. This is particularly true of two aircraft flying closely spaced parallel paths with one aircraft turning into the other. As early as mid 1962, in an analysis of the Bendix technique, computer analysis showed that false alarm rate in high density areas was sensitive to air traffic control practices employed by FAA. Work by Collins, broadened to include simulation of other collision avoidance systems, is nearing completion.

A promising result of the computer study was the growth potential inherent in the time and frequency technique.

## APPENDIX II

### ADSA CHRONOLOGY

#### 1. Established COPAG - First meeting April 1959

Members represent major civil and military users of airspace. The members provide the FAA with their requirements which the agency considers in formulating its Programs in this area. In addition, COPAG is a vehicle for obtaining advice and providing resources to achieve suitable airborne collision prevention means through available funds, personnel and facilities.

The ADSA program consists of three principal activities:

- 1) Conspicuity Enhancement (CE)
- 2) Pilot Warning Instrument (PWI)
- 3) Collision Avoidance System (CAS)

The visual/nonvisual chronology follows:

II-1

<u>WHAT</u>	<u>WHEN</u>	<u>CE/PWI</u>	<u>RESULTS</u>
2. Applied Psychology Corp. - Conspicuity Enhancement 529K	1959 - 1964		<p>a) Optical Aids - no single aid found to be of significant assistance.</p> <p>b) Visible Trails - not practical due to weight, unreliable nature of signal, hazards to aircraft and communities and installation maintenance requirements.</p> <p>c) Paints - Patterns and benefits were defined but associated costs have precluded wide-spread use.</p> <p>d) Pilot Judgment of Range and Altitude Separation - results showed need for supplementary aids and training, also improved pilot's capability.</p>

<u>WHAT</u>	<u>WHEN</u>	<u>RESULTS</u>
		c) Exterior Lighting - offers best potential for supplementing pilot's unaided visual capability, e.g., in addition to improved detectability, lights can provide for information transfer of maneuver, speed, altitude, sector, etc., information.
3. Cornell Aero Lab - Visual simulation 35K	1960	Designed simulation experiments to determine pilot performance under various flight geometries.
4. Sperry - Determination of PWI requirements 148K	1961-1964	Demonstrated that PWI information significantly improved see and be seen performance at slow speeds. Bearing information appears to be the most significant parameter.
5. Naval Ordnance Lab - Infrared PWI tests (COPAG)	1961-1962	PWI Requirements exceeded the state-of-the-art of applicable IR techniques.
6. Motorola - 135 MHz cooperative PWI 85K	1961	Test results were unsatisfactory and did not support further effort due to the added user complexity and costs that would be required to correct deficiencies.

CAS		<u>RESULTS</u>
<u>WHAT</u>	<u>WHEN</u>	
7. Bendix - One Way, Cooperative CAS 578K	1958-1962	Demonstrated the technical feasibility of the Tau criteria for CAS. The one way ground bounce technique was limited due to terrain induced perturbations, sophisticated computer requirement and non-real time data processing which limited adequate performance in maneuvering flight.
8. Sperry - Interrogator transponder, compatible PWI/CAS 445K	1960-1963	Lab tests demonstrated a modified threat logic, real time data processing and the PWI capability. Limitations included communication capacity problem and an expectation of a large, complex, high cost production item. Further development and flight tests not conducted due to potential advantage offered by the T/F techniques that were being investigated concurrently.
9. National Company - Synchronized T/F CAS Technique 73K	1962-1964	The T/F feasibility was demonstrated utilizing Tau criteria in a real time mode of operation with maximum communication capability. Potential benefits relative to many ATC functions appeared to be a fall out.
10. Collins - CAS Computer Simulation 310K	1963-1968	Preliminary investigation of T/F CAS/ATA interaction indicates no serious problems. Logics for maneuvering flights have been identified. Preliminary design parameters have been established and associated values are presently achievable.

## OVER-OCEAN SEPARATION ASSURANCE SYSTEMS

<u>WHAT</u>	<u>WHEN</u>	<u>RESULTS</u>
These are not PWI or CAS systems. They are included due to their separation function.		
11. ARN-52 (loan from Navy) Air-to-Air DME AIL (Beacon 98K - Range Altitude Monitor National Co. (T/F) 297K - Range Altitude Monitor	1966-1967	Simulation to develop operational procedures when utilizing the specified air-to-air equipment configurations has been completed with favorable results. Final reports have been published.

Obviously, additional costs have been incurred in effort to date - examples include management costs, flight testing of equipment such as Motorola and Bendix, and in-house analyses such as those conducted in accordance with the PWI requirements. This latter has raised interesting questions which might have a significant impact on the development of a practical, self-contained PWI. Basically, the point is that effective evaluation can only be accomplished at ranges less than was originally thought. Additionally, we have been spending a large percentage of our available time in the past two years with the ATA CAS Technical Working Group.

Looking at it another way - since 1958 this Program has not contributed to any regulation changes or equipment implementation.

However, this should not be misinterpreted to mean that significant advances have not been made. Due largely to the previously cited CAS activity, we have now reached the point where several manufactures are fabricating CAS equipment for airline/FAA evaluation scheduled for summer of 1969. The Program has the active support of the airlines and analysis indicates that previously encountered technical and operational problems can now be solved.



### APPENDIX III

#### C. THE STATUS OF PWI PROJECTS

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##### I. ABSTRACT

An FAA sponsored symposium was held in December 1967 to encourage development of a "Pilot Warning Instrument." Status of past, present, and future programs was indicated. Progress in the development of PWI will be the subject of this presentation.

National Aeronautics and Space Administration (NASA), Langley Research Center is conducting a program consisting of analytical and experimental studies specifically directed towards the evaluation of proposed warning systems and a specific doppler radar technique. NASA/Electronics Research Center has reported on another PWI technique, the Electro-Optic (Infrared) System. FAA's contract for visual illusion, aircraft exterior lighting, quantitative PWI criteria, and separation standard studies is in progress as is the one year study program on "Near Mid-Air Collisions." We have recently completed a program that provided data to support a low-cost training device that would improve the visual search time of pilots by use of improved scan techniques, in conjunction with normal workloads in the cockpit.

The equipment characteristics for PWI will be identified, as they are known today; and as presented, they offer only a partial solution to the potential developers and users.

##### II. INTRODUCTION

This presentation will indicate the status of selected Pilot Warning Instrument (PWI) programs within specific government agencies. Technical content or description will be limited to allow a general summary of all significant PWI programs. A review of the FAA "near-miss" studies and preliminary PWI equipment characteristics will be accomplished.

Using the FWI Symposium in December 1967, as a baseline, significant activity is in progress for the development of a "Pilot Warning Instrument (PWI)". The referenced symposium presented the status of FWI activities to December 1967, and that status is now reflected in AD 666-122, "Pilot Warning Instruments, Proceedings of a Symposium," available from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151. (\$3.00 per copy)

As a brief summary, let's review what FWI is all about. The definition of FWI as agreed upon by the Collision Prevention Advisory Group (COPAG), composed of representatives from both government agencies and selected civil aviation associations (i.e. FAA, NASA, AF, Navy, Army, ATA, AOPA, NTSB, ALPA, NBAA, NPA) is as follows:

"A pilot warning instrument is an airborne device whose function is to warn a pilot and provide him with information suitable to assist him in visually locating other traffic in his general area."

With a FWI, the pilot is provided with a warning of the existence of other aircraft and in addition may be supplied with some other information to assist him in evaluating the situation, i.e. information such as the relative bearing to the other aircraft, or its relative altitude or range or any combination of these parameters; however, by the definition, with a FWI, the pilot is the computer and it is he who must evaluate the threat, select a course of action and execute same. The following is a summary of the specific government program and general status:

### III. PWI PROGRAM STATUS

- A. National Aeronautics and Space Administration (NASA) - Electronic Research Center - Dr. Charles Leigh has previously reported on the studies and development of Electro-Optic (Infrared) PWI components and systems. FAA will not provide any further comments, although at this point we may note, that FAA is working closely with all government organizations including NASA/ERC, NASA/LRC, Army, etc., to provide a continuing technical and data exchange for mutual FWI benefits.

It has been found, where FAA requires technical support in areas not familiar, i.e., Infrared, Lasers, etc., NASA organizations have provided this interface and consultation. In reverse, FAA has provided the operational data and information in support of NASA and other government organizations in FWI equipment.

- B. NASA - Langley Research Center - Langley Research Center is conducting a program consisting of analytical studies of a general nature with respect to the development and evaluation of warning systems, and analytical and experimental studies specifically directed towards the evaluation of a proposed cooperative doppler technique, PWI. The current status of this work is as follows:

1. Analytical Studies-

- a. The first requirement for conducting analytical studies is to obtain a definition of the flight environment in which such systems must operate. Through the efforts of FAA personnel at NAFEC, data has been obtained which provides the flight time histories of all radar-tracked aircraft in the Atlanta area over a 12 hour period.
- b. An initial computer analysis of this data has been made to determine some of the statistics of the flight environment such as the distribution of the values of range, closing velocity, and altitude separation which were encountered.
- c. Work is presently being conducted to provide a more detailed study of the performance which could be expected with various types of systems in this environment. This is being accomplished by determining the error rate (false alarm) which would exist with various warning criteria such as range only, range-altitude, range-velocity, etc.

Statistical curves will be plotted with these types of alarms criteria, vs probabilities of unnecessary alarms. With this set of data, it will be possible to look at any number of potential PWI approaches, if based on alarm criteria (i.e. range, altitude, relative angle, etc.), and determine under any number of intruders what the probabilities of false alarms are, and from that analysis, determine the advantage or disadvantage in pursuing it further.

Statistical curves and other data will be available on completion of NASA/LRC's program.

- d. Also, a detailed computer model of the cooperative doppler system is being prepared which will be used in conjunction with this data to determine the performance which can be obtained in a realistic environment.

## 2. Experimental Program -

- a. The experimental program is being conducted to determine what implementation problems exist and to measure the actual equipment performance. The system is based on a cooperative, two-frequency cw doppler interrogated/transponder concept as in Figure A. The primary information provided to the pilot is the closing velocity derived from doppler shift and approximate direction angle derived by antenna lobing. A functional diagram is as shown in Figure B. The received signal power varies as the 6th power of the range, providing an approximate measurement of range. (This is due to the squared variation in the transmission, the square relationship in the multiplier, and the squared variation in the retransmission). This range measurement in conjunction with closing velocity is used to control the system sensitivity and thus determined false alarm rate. Random coding is employed to allow all aircraft to operate on the same frequency assignments. Assignment of codes or frequencies for individual aircraft is not necessary. The NASA/LRC primary goal is to develop a simple system and one which could be produced at relatively low cost.
- b. Design and construction of the prototype equipment is nearly complete and the equipment is undergoing laboratory evaluation. However, final evaluation is being held up due to the delivery of some components. Preparations have been initiated for the installation and flight testing of this equipment in two aircraft. Generally, November or December should see the actual start of this flight program.

Figure C offers a few general advantages and limitations of this type PWI.

Langley Research Center is investigating this technique as one possible approach to the collision-hazard warning problem. LRC work has not developed to the point where they can define the detailed performance of various equipment configurations or their cost in dollars. You can see, however, that the transponder is relatively simple with the major items being the antenna and a linear amplifier. LRC is continuing performance analyses of this concept with particular attention to the saturation problem, and are also investigating some of the practical implementation problems.

# SYSTEM CONCEPT

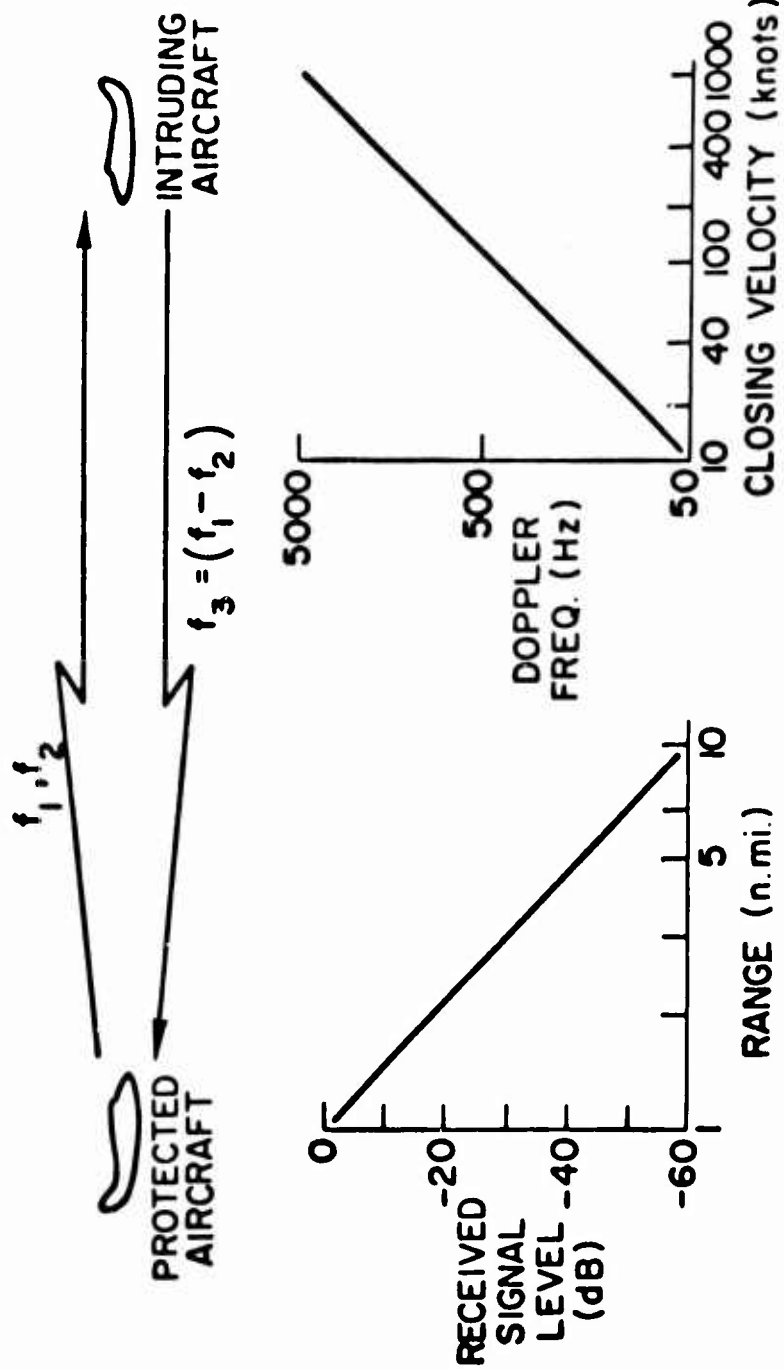
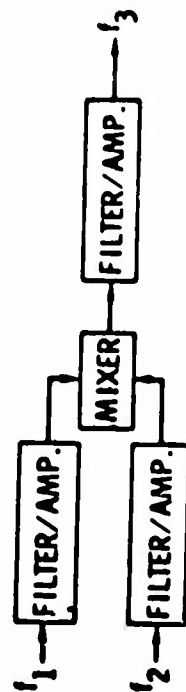
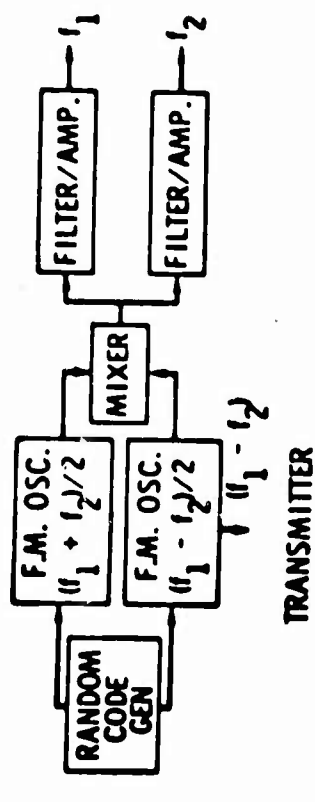


FIGURE A

# FUNCTIONAL DIAGRAM



## TRANSponder

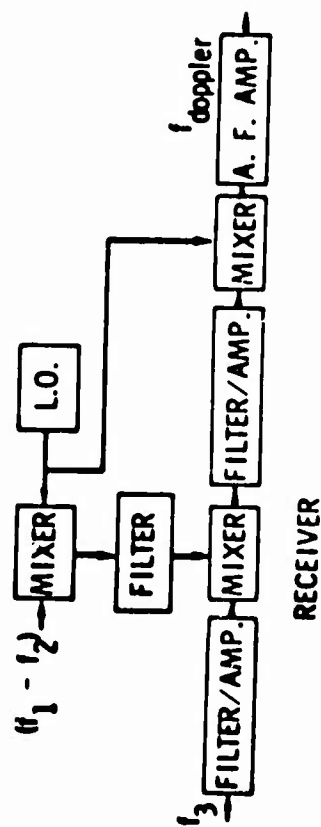


FIGURE B

## ADVANTAGES

1. ADAPTABLE TO VARIOUS DEGREES OF PROTECTION.
2. INDIVIDUAL CHANNEL ASSIGNMENTS NOT REQUIRED.
3. PRECISION CONTROL OF FREQUENCY NOT REQUIRED.
4. RELATIVELY LOW COST.

## LIMITATIONS

1. RETURNS FROM MULTIPLE AIRCRAFT WITH IDENTICAL CLOSING VELOCITIES ARE NOT SEPARABLE.
2. ACCURACY OF RANGE DETERMINATION.
3. POSSIBLE SYSTEM SATURATION.

FIGURE C

- C. U. S. Army Board for Aviation Accident Research (USABAAR), Ft. Rucker, Alabama- In December, Major Ron Merritt (now Lt. Col. Merritt) reviewed the U. S. Army PWI requirements at Ft. Rucker. In summary of that presentation, Major Merritt indicated the Army's serious concern of mid-air collisions which are in areas of high density operations, the training mission. Basically, the mid-air accidents occurred between Army aircraft of the same type and flying the same mission; helicopters in basic instrument training have contributed to the highest percentage of these accidents.

The basic requirements indicated for a PWI system to operate within the Ft. Rucker environment is generally as follows:

1. High density training operation
2. Operate within low-closure environments
3. Buffer zone afforded each aircraft should not exceed 2000 feet horizontal and  $\pm$  300 feet vertically.
4. Weight 10 lbs. maximum
5. Display to provide positive means of warning the pilot.
6. Low-cost

Early in the spring of this year a number of manufacturers responded to a request by USABAAR to participate in a flight test program of "off-the-shelf" hardware, to determine the feasibility of providing PWI hardware to the specified requirements. Each manufacturer's system was test flown for a two week period, with data gathered for a comparative evaluation, and to provide data on the feasibility of the technique.

The results were encouraging, in fact, so encouraging that two manufacturers have agreed to participate in another evaluation in October and November. One manufacturers system is an adaptation of the radar altimeter, with the other manufacturer utilizing a interrogator/transponder approach. Both systems provide for visual/aural warning displays.

The USABAAR approach is applicable to a specific environment and is acceptable for the training mission.

- D. FAA - National Aviation Facilities Experimental Center (NAFEC) - There are two basic PWI programs at NAFEC which are oriented to help the pilot on the ground and in the air, including the development of criteria, techniques, or hardware for potential PWI candidates.



1. Low-Cost Collision Avoidance Ground Training Equipment - This program was just completed in July 1968, and the Final Report No. NA-68-37 entitled, "Evaluation of Low-Cost Collision Avoidance Ground Training Equipment," is within its final stages of completion.

The objective of this project was to determine the effectiveness of such a system of low-cost aids and procedures in improving visual search by improved scan/search techniques while performing normal VFR task requirements.

Previous studies and most of our own practical experience indicates that a rather small amount of the total time available is spent looking outside the cockpit of modern aircraft. Training in "time-sharing," or the division of attention between inside-the-cockpit duties and outside-the-cockpit search for other aircraft is an additional need to support the "see and avoid" concept. The conclusions reached on these studies indicated that if visual attachments were used with today's flight simulators, a significant contribution could be made to a pilot's overall skill and the ability to detect intra and extra cockpit emergencies.

FAA's Cessna single engine flight simulator, Figure 1, fully instrumented, situated in the center of a partial sphere of 10 feet radius, was the test configuration. The pilot had virtually the Cessna visual capabilities from the side door, front windshield, to the opposite side door. The luminance of the dome was varied for above horizon brightness, and below horizon fade-off.

The device being tested, constituting intruder aircraft or targets to be detected, was displayed as real aircraft images by the use of a 35 mm magazine load, slide projector with a 3" lens. This projector was suspended above the cockpit on a TV rotor, Figure 2. Remote control could change direction or azimuth of projector, and could also provide timing increments of a shutter to vary exposure of the image to the pilot, Figure 3. These intruder aircraft images varied in simulated wing span dimensions and viewing distances.

With a set script of 10 training sessions (lasting 35-40 minutes each) which consisted of a local VOR cross-country flight, FAA student, private, and professional pilots participated. After the series of 10 training sessions, pooling of the general score is as shown in Figure 4.

Other data gathered from this program included percentage of detection by target size, detection as a function of elevation and brightness, and others.



FIG. 1 SIMULATOR SITUATED IN THE DOME

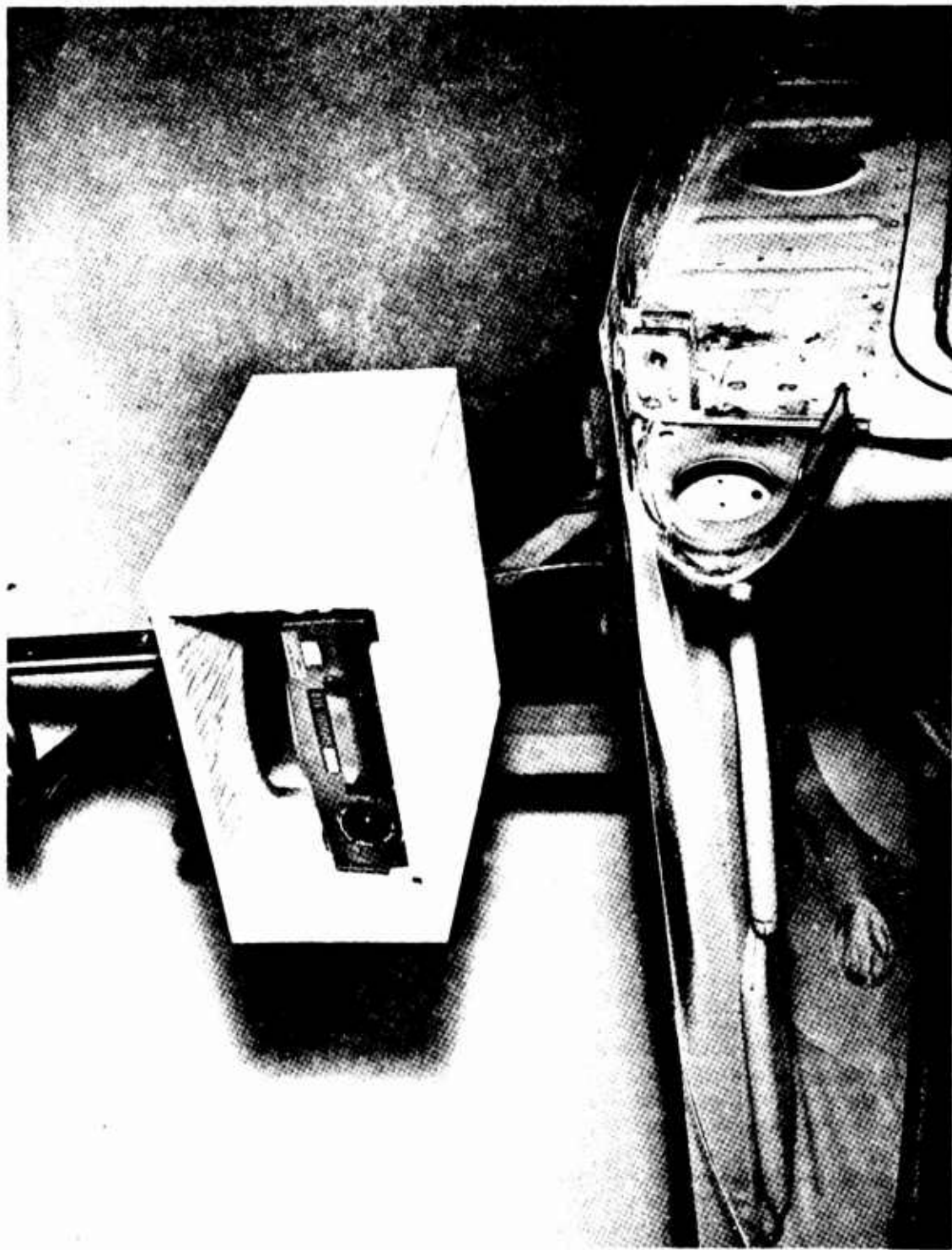


FIG. 2 PROJECTOR SUSPENDED FROM THE ANTENNA ROTOR



FIG. 3 SIMULATOR OPERATOR'S POSITION AND PROJECTOR CONTROLS

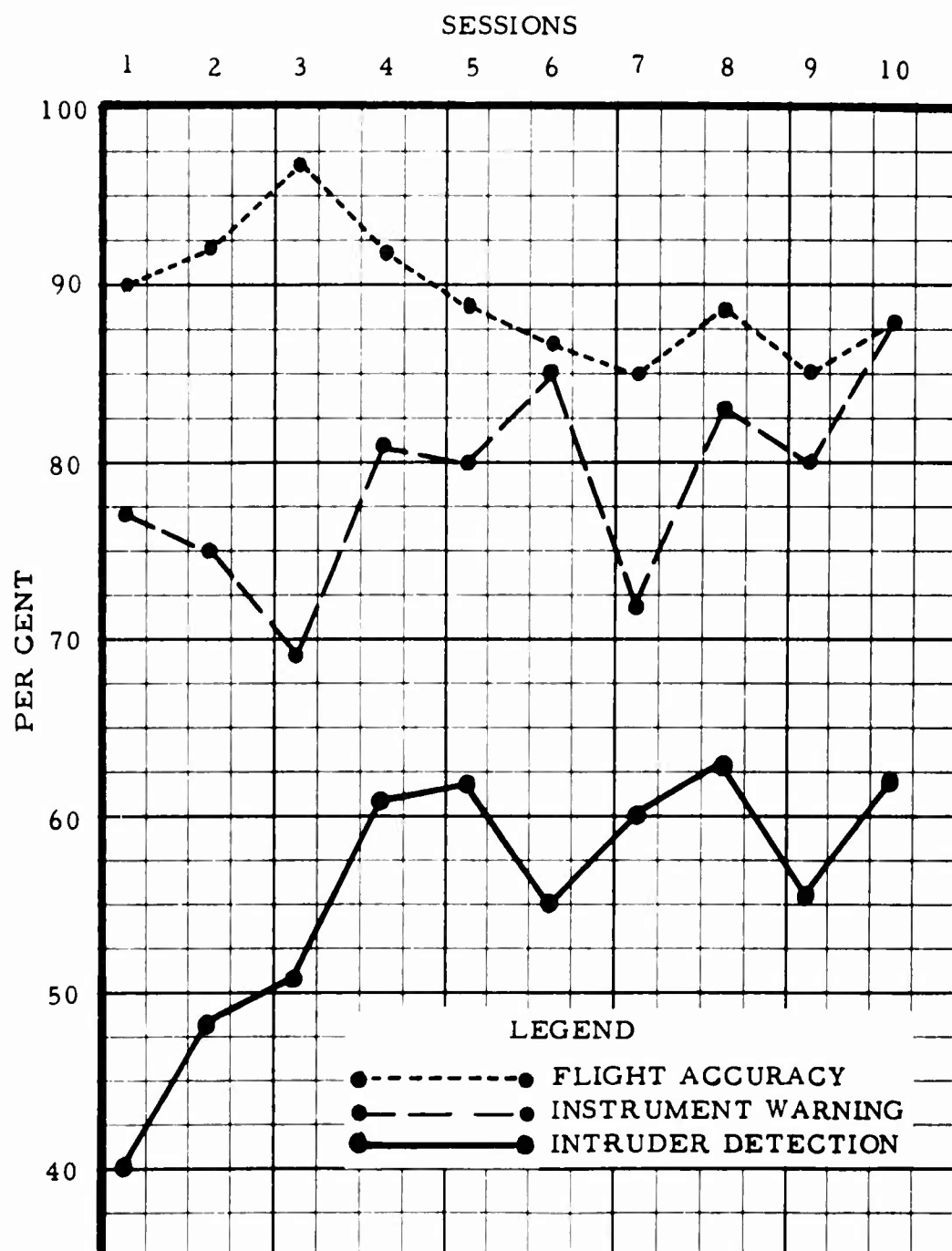


FIG. 4 DETECTION SCORES, FLIGHT CONTROL SCORES, AND MALFUNCTION INDICATION SCORES BY SESSIONS

This approach has shown the practical use of this device and the benefits that would be gained in pilot training at many of our training facilities.

FAA is presently planning to develop a number of packages to offer to flight training schools, both civil and military, for the purpose of verifying the validity of the equipment and the time sharing practice program.

2. Analysis of Visual Separation Techniques - This program is in its beginning phases scheduled for completion in about 18 months by Rowland and Co. of Haddonfield, New Jersey. So with it just beginning, a review of the objectives will be briefly stated. The contract will attempt to provide for:
  - a. The determination of the effectiveness of the "see-and-avoid" concepts of aircraft separation, by analytical and simulation techniques. Review of all previous work efforts related to the visual illusion problems experienced in flight which result in spatial disorientation will be accomplished. Recommendations of additional work or tests that may be performed to provide information or techniques in illusion solving cues is expected to result.
  - b. Recommendations for standardization of aircraft exterior lighting. As we all know this is a controversial subject, especially with the techniques now available of flashing red lights, flashing white lights, xenon strobes, etc. As a result of this study it is hoped that we can proceed to a modern system to aid in PWI search concepts.
  - c. The investigation of aircraft separation standards in FAR 91, Part B (aircraft to cloud) to determine their adequacy.
  - d. Development of quantitative criteria for PWI. Develop specifications and a flight test plan for the PWI. This is one of the primary phases of this contract. Granted a preliminary specification or characteristic is known and is generally being used today as a guideline, a major phase of this program will be to determine what information will be most beneficial to a pilot under many situations.

With this program, FAA expects to supplement the PWI approaches taken or be able to provide data to all designers that our criteria and characteristics of today are valid.

E. FAA Near-Midair Collision Study -

On January 1, 1968, FAA instituted a one year study of near midair collisions and invited (on a no penalty basis) all pilots, controllers, and other persons involved to participate in the reporting of these "near misses". Response to the invitation has been extremely encouraging.

The task of classifying all this information into useful tools is being accomplished by an experienced team of FAA pilots, air traffic controllers, and operations research analysts. The processing of each report can provide as many as 250 distinct pieces of information which are sorted, grouped, and entered on computer magnetic tapes. These code 250 data elements describing the most pertinent operational factors, problem areas, cause of near-miss, plus a summing of the traffic advisory situations will permit computer correlation of selected factors best describing the circumstances under which near-miss incidents are occurring.

Initial classification areas include the following:

1. Enroute/Terminal Traffic
2. Type of Flight Plan
3. Altitude Levels
4. Radar Service/positive control involved
5. Operator involvement
6. Convergence on NAVAID and/or Airport
7. Phase of Flight

The primary breakdown separates the classification areas into three categories:

1. No Hazard - This group includes all incidents where the pilots had ample time to judge the possibility of a conflict and to alter course without difficulty.
2. Potential - These potential incidents are those which required immediate evasive action to avoid a collision.
3. Critical - Critical incidents are "NEAR-MISSES" which did not allow time for evasive action, and where disaster was averted by chance rather than by procedure.

With the one year of data gathered, at the conclusion of 1968, and the data reduced, a report will be available prior to

May 1, 1969. This study will provide not only insight as to what the conditions of the greatest hazard are, but also will provide various data for use in the design and development of collision prevention devices and the improvement of communication systems, air traffic control systems, etc.

Generally these data include, as a minimum:

1. Closure Rates - at various altitudes
2. Relative Bearing -
3. Relative Altitude - Vertical separation, climb/level, descend/level, level/level, etc.
4. Range - at first sighting; at closest proximity
5. Bearing and elevation angle rates -
6. Time - relative to sighting vs pilot response
7. Elevation angles -

With the above data, information will be available as to what caused alert (lights, color, noise, smoke, etc.), VFR/IFR conditions, day/night, and others.

FAA appreciates the conscientiousness, continuing cooperation, and promptness of all those parties involved in filing these reports. It has been pointed out by the FAA analysts that a pilot who has experienced a "potential" or "critical" near-miss is usually eager to participate in this program.

"Most pilots do not have to be told twice -- no one is more interested in contributing to aviation safety than those who fly regularly-" David Gelfan, FAA Office of Information Services.

#### VI. PWI EQUIPMENT CHARACTERISTICS

In PWI Symposium Proceedings, the "best estimate" equipment characteristics were defined. The following is a summary of those characteristics:

1. VFR Operations
2. Non-cooperative is ideal, but as a minimum, cooperative



3. Satisfactory operation in a multi-aircraft environment (Airport Terminal Area).
4. Azimuth Accuracy (relative to equipped aircraft heading)  
 $\pm 10-15^\circ$
5. Azimuth Coverage  
 Minimum: Nose  $+ 45^\circ$   
 Desired: Nose  $\pm 100^\circ$   
 Ideal :  $360^\circ$
6. Elevation Accuracy (relative to equipped aircraft altitude)  
 $\pm 5^\circ$
7. Elevation Coverage  $\pm 10^\circ$
8. Range  
 2-3 mile at 150 kts } partial solution  
 5-6 mile at 300 kts }
9. Altitude - sea level to user practical altitude levels
10. Weight - 15-25#
11. Power - 100-150 watts
12. Cost - \$1500-\$3500
13. Visual Display

No attempt is made here to define any appropriate display due to the various combinations of PWI parameters possible. Any display should be human engineered to maximize the benefits that the PWI provides to the pilot.

The above characteristics are the first cut requirements and offer only a partial solution but are of interest to owners of aircraft that have varying degrees of performance.

#### V. SUMMARY

Within this technical convention a number of proposed systems and techniques have been presented. Where do you, the designer, manufacturer, and user stand in relation to PWI?

On conclusion of the PWI Symposium in December 1967, a questionnaire was sent out to the attendees to obtain an indication of the audience's reaction or response. Generally, there was some hesitancy to admit that a PWI is economically feasible, and that a non-cooperative PWI was within the state-of-the-art. However, at least 50% of the responses have current or planned "in-house" programs!

PWI as an airborne device, to aid pilots in evaluation of conflicts, should be pursued by industry to: conduct "state-of-the-art" searches of technology, help define potential system specifications, design, build, and test promising techniques.

But whatever the solution(s) are, it is FAA's desire to encourage any individual or organization to pursue the development of an adequate "Pilot Warning Instrument" for the safety and efficiency of the airways.

## APPENDIX IV

### D. Questionnaire Distributed August 1968 and Reply Matrix

#### Questionnaire

1. To what extent is your organization involved in precision time-frequency technology?
2. What level of effort (manpower assigned) is maintained at your organization in time-frequency technology?
3. Is your time-frequency involvement theoretical, analytical, or hardware-oriented?
4. What particular time-frequency oriented programs are you currently involved in? Under what sponsorship? What classification?
5. What facilities do you have or operate peculiar to precision time-frequency techniques?
6. Have you been otherwise involved in the avionics aspects of communications, navigation, air traffic control, etc.?
7. Is your organization prepared to suggest or propose new approaches to clock synchronization, epoch setting, or other aspects of world-wide time-keeping in the microsecond regime?
8. Can your organization participate in consultive meetings with the FAA on time-frequency matters without formal financial support? To what extent?

ORGANIZATION	T/F INVOLVE- MENT	T/F ORIENT- ATIONS	PROGRAM	SPONSOR	CLASS- IFIC.	FACILITIES	AVIONICS COMM. NAV. ATC	NEW AP- PROACH	CAN PARTICI- PATE
AFSC	Yes. See program.	Theoretical Analytical Hardware	Communications, identi- fication and navigation programs.  See Note.	USAF	Not	given			yes
Note: Additional information to be furnished on or about September 2, 1968									
NAPS	World-wide calibration headquarters including Precise Time and Time Interval (PTTI)	Hardware oriented	Precise time and fre- quency calibration for the Air Force.	USAF	Not given	Cesium beam clocks.  LORAN-C receivers with portable clocks and assoc. equipment.	No	New methods of clock synch under study	Yes. Yes. to some extent

ORGANIZATION	T/F INVOLVE- MENT	T/F ORIENT- ATION	PROGRAM	SPONSOR	CLASS- IFIC.	FACILITIES	AVIONICS COMM., NAV., APPROACH	NEW AP- PROACH	CAN PARTICI- PATE
John Hopkins University, Applied Physics Lab.	Precision time and frequency satellite navigation and geodesy	Theoretical Analytical Hardware	Navy navigation satel- lite program utilizing doppler principle, thus requiring pre- cision time and fre- quency control.	Navy	Most uncl. part secret	1-Cesium standard 1-Atomichron 2-Rubidium standards 4-Crystal standards 2-Portable clocks	NAV ATC	yes	yes, to some degree.
			Geodesy research programs dependent on doppler tracking methods. The geodesy satellites are tracked by a world-wide track- ing network (TRANET) which is time-synchro- nized by satellite- borne clocks.	Navy					
			Some scientific space programs.  (About 15 engineers and technicians full time).	NASA					

ORGANIZATION	T/F INVOLVE- MENT	T/F ORIENTI- ATION	PROGRAM	SPONSOR	CLASS- IFIC	FACILITIES	AVIONICS COMM., NAV., ATC, PROACH	NEW AP- PROACH	CAN PARTICI- PATE
USCG	LORAN-C Stations synchroniza- tion, cali- bration, monitoring.	Mainly analytic and hard- ware.	LORAN-C stations. Currently developing and installing equip- ment in LORAN-C chains to allow time dissemina- tion from USNO to Europe.	Naval observa- tory	Uncl.	LORAN-C stations	yes	Prop- osed ap- proach to clock sync. using LORAN-C	yes
			Synchronization of LORAN-C to UTC. Has developed equipment necessary for self- monitoring and synchro- nization.  (2 engineers, 40% of their time).						

ORGANIZATION	T/F INVOLVEMENT	T/F ORIENTATION	PROGRAM	SPONSOR	CLASSIFICATION	FACILITIES	AVIONICS COMM., NAV., ATC	NEW APPROACH	CAN PARTICIPATE
USNO	Time Service Division exclusively involved in precision time-freq.	Theoretical Analytical Hardware	Multiple military and civilian, international and domestic.  (50 people)	CNO DOD	Not given	Not given	yes	yes	yes
NBS	Operation and maintenance of stations WWV, WWVL, WWVH, and WWVB.	Theoretical Analytical hardware	Research on use of satellites and VLF signals as means of time and frequency dissemination.  Basic studies of hydrogen MASER.  Theoretical studies of noise processes as they affect time and frequency technology.  (50 people)	Not given. (Gov't and Industry)	Not given	Hydrogen MASERS.  NBS Cs Beam Freq. Standard	No	yes	yes (Major research effort would require support)

ORGANIZATION	T/F INVOLVE- MENT	T/F ORIENT- ATION	PROGRAM	SPONSOR	CLASS- IFIC.	FACILITIES	AVIONICS COMM., AP- PROACH	CAN PARTICI- PATE
Army Ft. Monmouth, N. J.								
Mallard	Two Contracts (see program)	Theoretical Analytical Hardware	Bit Synchronization- atomic clock vs. fre- quency averaging. (1 man part time)  Timing and framing for troposcatter and line of sight (LOS) communi- cations (3 men part time)	US Mallard Project Management Office	Uncl.	None at present peculiar to T/F.	No.  No. Ap- proach not yet devel- oped.	yes. On observer basis. Possible tech. contrib.
USAECON	Most aspects of precision time-fre- quency tech- nology	Theoretical Analytical Hardware	See Note 1	USAECON	Part class- ified Confid.	See Note 2	yes. R & D for Army and synch.	yes
Note 1:	(1) Study of effects of the synchronization (2) Quartz crystal and molecular frequency control, eval., and application of precision frequency control devices, extension of freq. control to the infrared, rubidium gas cell research and thallium beam tube R & D. (3) Improved Army air traffic regulation systems under which TOTES and STARS programs are performed. (4) TOTES - Time-ordered techniques experimental system; STARS - Synchronized Time Automated Reported System).							
Note 2:	10- VLF phase tracking sites, 25- TRACOR receivers and associated test equipment and multichannel recorders, hydrogen MASERS, cesium standards, rubidium standards, quartz crystals, LORAN-C receiver, nanosecond pulse interval counter, time slot generator, 2- microwave wide-band receivers special for T/F, precision crystal and rubidium clocks.							



APPENDIX V

Questionnaire December 1968

1. As a result of the presentations and discussions at the meeting, have your opinions as to establishing and maintaining common time synchronization changed? If so, how?

2. Do you believe that obtaining precision time/frequency as a superimposed secondary mission to navigation and communication service is a desirable approach?

If yes, why - economy, simplicity, transitional ease, etc.

If no, why - compromise, inefficient, etc.

3. If, as currently planned, the FAA establishes a network of ground stations synchronized to a common time to within  $\pm .5 \mu s$ , do you envision any possible use of this network to your organization? If so, would such possible use influence the design of the ground stations? How?

4. Do you envision any requirements by your organization for synchronized time to an accuracy greater than  $\pm .5 \mu s$ ?

5. Do you have comments concerning the "Typical Ground Station Timing Scheme," recommended by Dr. Winkler?

6. Do you feel that utilization of world-wide linear time from atomic devices would compromise operation of navigation, communications, or other facilities utilized by your Service?

7. Do you agree that U.S. National Standards are essential to insure operation of a T/F - CAS?

Do you feel a study group, representative of all users, should start coordination of requirements for a U.S. National Standard at this time?

Who do you recommend as a knowledgeable service representative?

8. Do you feel that terminology standards should be compiled at this time? Can your Service provide terminology standards currently in use?
9. After reviewing the information presented, do you believe another meeting on the subject would be fruitful?

Please answer and remove these two questionnaire pages and return in the self-addressed envelope.

<p>UNCLASSIFIED</p> <p>1. FD-200 Area</p> <p><u>Descriptors</u></p> <p>Time/Frequency Collision Avoidance Systems</p> <p>Utilization of Time/Frequency in Collision Avoidance Systems</p> <p>Federal Aviation Administration, Systems Research and Development Service, Washington, D. C.  <b>UTILIZATION OF TIME/FREQUENCY TECHNIQUES IN COLLISION AVOIDANCE SYSTEMS</b>  August 27-28, 1968</p> <p>Unclassified Report</p> <p>A two-day meeting held on August 27-28, 1968, at the Federal Aviation Administration, Washington, D. C., discussed the "Utilization of Time/Frequency Techniques in Collision Avoidance Systems." Participating organizations were Government agencies active in the field of time/frequency application.</p> <p>Presentations made at the meeting, complete or in summary, are included in this publication.</p> <p>The attendees suggested that a summary of past and present FAA projects for Pilot Warning Instruments (PWI) and Collision Avoidance Systems (CAS) be attached to the minutes for general information. Appendix I contains (over)</p> <p>UNCLASSIFIED</p>	<p>UNCLASSIFIED</p> <p>1. FD-200 Area</p> <p><u>Descriptors</u></p> <p>Time/Frequency Collision Avoidance Systems</p> <p>Utilization of Time/Frequency in Collision Avoidance Systems</p> <p>Federal Aviation Administration, Systems Research and Development Service, Washington, D. C.  <b>UTILIZATION OF TIME/FREQUENCY TECHNIQUES IN COLLISION AVOIDANCE SYSTEMS</b>  August 27-28, 1968</p> <p>Unclassified Report</p> <p>A two-day meeting held on August 27-28, 1968, at the Federal Aviation Administration, Washington, D. C., discussed the "Utilization of Time/Frequency Techniques in Collision Avoidance Systems." Participating organizations were Government agencies active in the field of time/frequency application.</p> <p>Presentations made at the meeting, complete or in summary, are included in this publication.</p> <p>The attendees suggested that a summary of past and present FAA projects for Pilot Warning Instruments (PWI) and Collision Avoidance Systems (CAS) be attached to the minutes for general information. Appendix I contains (over)</p> <p>UNCLASSIFIED</p>
<p>UNCLASSIFIED</p> <p>FAA PWI-CAS projects. Appendix II contains ADSA Chronology, and Appendix III contains the status of PWI projects.</p> <p>As part of the initial correspondence to respective attendee organizations, replies were solicited for a number of questions. Appendix IV contains the August 1968 questionnaire and a matrix of replies received.</p> <p>Appendix V contains a December 1968 questionnaire for your reply. Answers to this questionnaire may provide guidance and direction to the FAA as to logical development of the aviation ground facilities required to disseminate "time" for airborne T/F CAS equipment.</p> <p>UNCLASSIFIED</p>	<p>UNCLASSIFIED</p> <p>FAA PWI-CAS projects. Appendix II contains ADSA Chronology, and Appendix III contains the status of PWI projects.</p> <p>As part of the initial correspondence to respective attendee organizations, replies were solicited for a number of questions. Appendix IV contains the August 1968 questionnaire and a matrix of replies received.</p> <p>Appendix V contains a December 1968 questionnaire for your reply. Answers to this questionnaire may provide guidance and direction to the FAA as to logical development of the aviation ground facilities required to disseminate "time" for airborne T/F CAS equipment.</p> <p>UNCLASSIFIED</p>